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VISUAL DETECTION OF TARGETS: ANALYSIS AND REVIEW

by

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ABSTRACT. This report discusses many of the aspects of air-to-ground visual search for targets. Curves are presented that can be used for estimating the probability that a ground target is within view and for determining the angular rate of the target as measured with respect to the air observer. Optical aspects (clouds, atmospheric attenuation, reflectance factors) of visual detection are discussed briefly and references from which data can be obtained are cited. A number of laboratory experiments concerning visual detection are described, and some of the results are given. Examples of simulation, operational, and mathematical methods of obtaining estimates of search performance are given and compared.

U.S. NAVAL ORDNANCE TEST STATION

China Lake, California

February 1965

U. S. NAVAL ORDNANCE TEST STATION

AN ACTIVITY OF THE BUREAU OF NAVAL WEAPONS

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FOREWORD

This study has been performed as part of the program of the Naval Ordnance Test Station in the field of weapon system development and analysis for conventional warfare.

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This report has received technical review by Roy Dale Cole, Consultant in the Aviation Ordnance Department; and Lewis O. Erwin, of the Weapons Analysis Group.

Information presented herein may be subject to revision as further data become available.

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CONTENTS

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INTRODUCTION

At present, one of the critical problems encountered in military operations is that of identifying ground targets from aircraft. The problem is more severe if the aircraft is flying low and fast. Search may be made either directly through the canopy or on a television or optical screen whose sensor is mounted on the aircraft. In any case, the problem is one of identifying targets moving with respect to the observer.

The purpose of this report is to discuss the geometric, kinematic, physical, and human engineering aspects of air-to-ground search. The results of pertinent analytic and experimental investigations are presented and briefly discussed. Although the value of these investigations is assessed, no attempt has been made to perform a comprehensive evaluation of each of them.

GEOMETRY OF AIR-TO-GROUND SEARCH

Two factors that affect the detection probability of a ground target from an aircraft are obstruction of the field of view by (1) the aircraft and (2) by the terrain surrounding the target. Both factors are geometric in nature and must be considered in determining the detection probability for any given situation.

AIRCRAFT OBSTRUCTION OF VIEW

The great increase in jet aircraft performance in recent years has been accompanied by a decrease in the ease of searching from such aircraft. The faster the aircraft and the sleeker the aerodynamic design, the poorer the view from the cockpit. This view limitation imposed by the aircraft is a function of the aircraft construction and the flying conditions, since angle of attack changes with aircraft loading, altitude, and velocity. The maximum line of sight depression angle has been measured for several aircraft in power approaches and is shown in Fig. 1. Data taken from Ref. 1 were used to plot the curves. If the aircraft is assumed to have a smaller angle of attack during a search flight, the curves would be raised somewhat. An example is shown by the A-4B depression angle dead ahead. If the angle of attack is close to zero, the dead-ahead point of the curve would be raised $8^{\circ}\ 42'$ to the point indicated by the dotted line in Fig. 1. Generally, the maximum dead-ahead depression angle for such aircraft varies between 10 and 20 degrees. This aircraft obstruction results in a large area benea '. the aircraft, blind area (shown in Fig. 2), which the pilot cannot see without maneuvering. For instance, in level flight at 1,000 feet altitude with a depression angle of 14 degrees, nothing can be seen

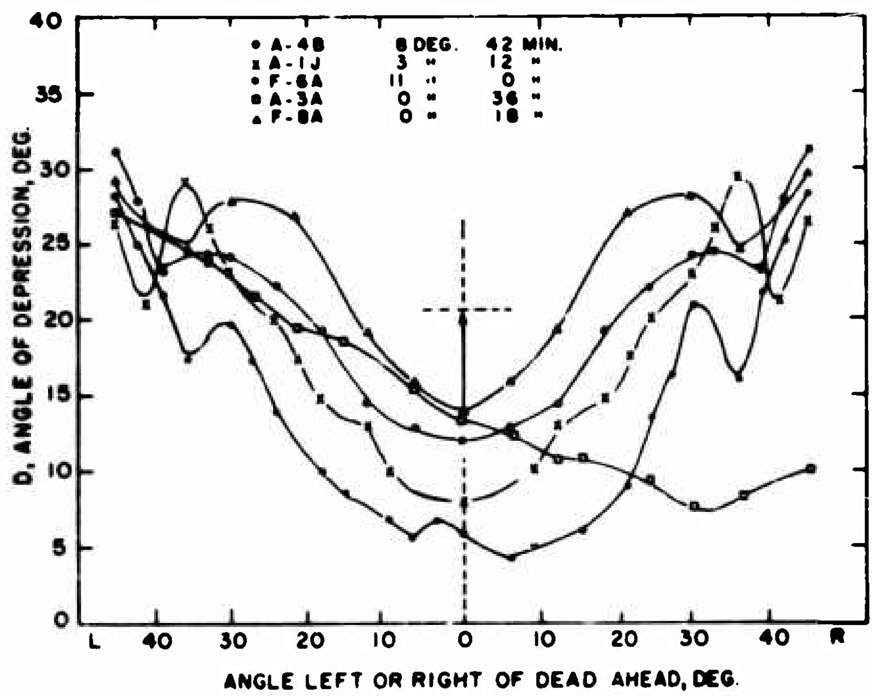


FIG. 1. Maximum Angle of Depression for Pilot Looking Out of Aircraft During Power Approach. Pitch angles during approach are nose up except for the A-3A (a two-place aircraft), which is nose down. The obstructive effects of some cockpit structures, gunsights, etc., although in some cases appreciable, are not shown in the curves.

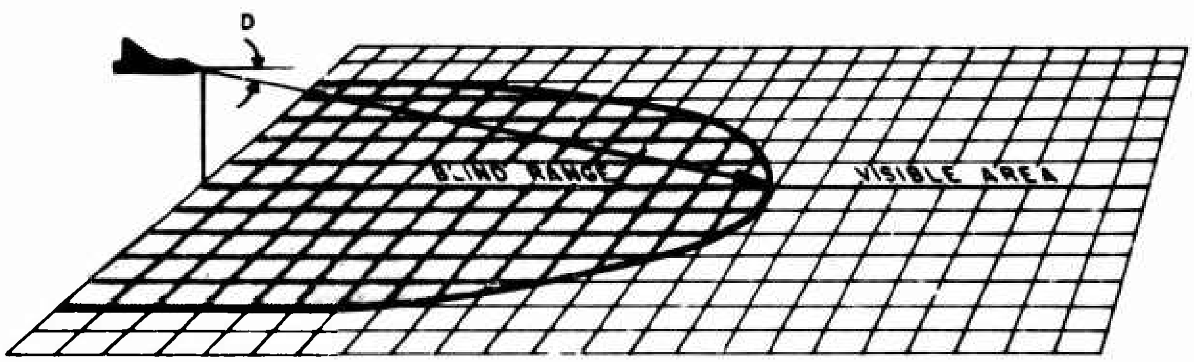


FIG. 2. Forward Area, Blind Range, Caused by Aircraft Obstruction.

dead ahead on the ground unless it is more than 4,000 feet ground-range ahead of the aircraft. Values of blind range can be taken from Fig. 3 for various depression angles and altitudes. This large blind area is one of the reasons pilots prefer to search through the side of the canopy, banking the aircraft during search. "S" turns are used often by the Navy (Ref. 2) and the Air Force when searching the ground for targets.

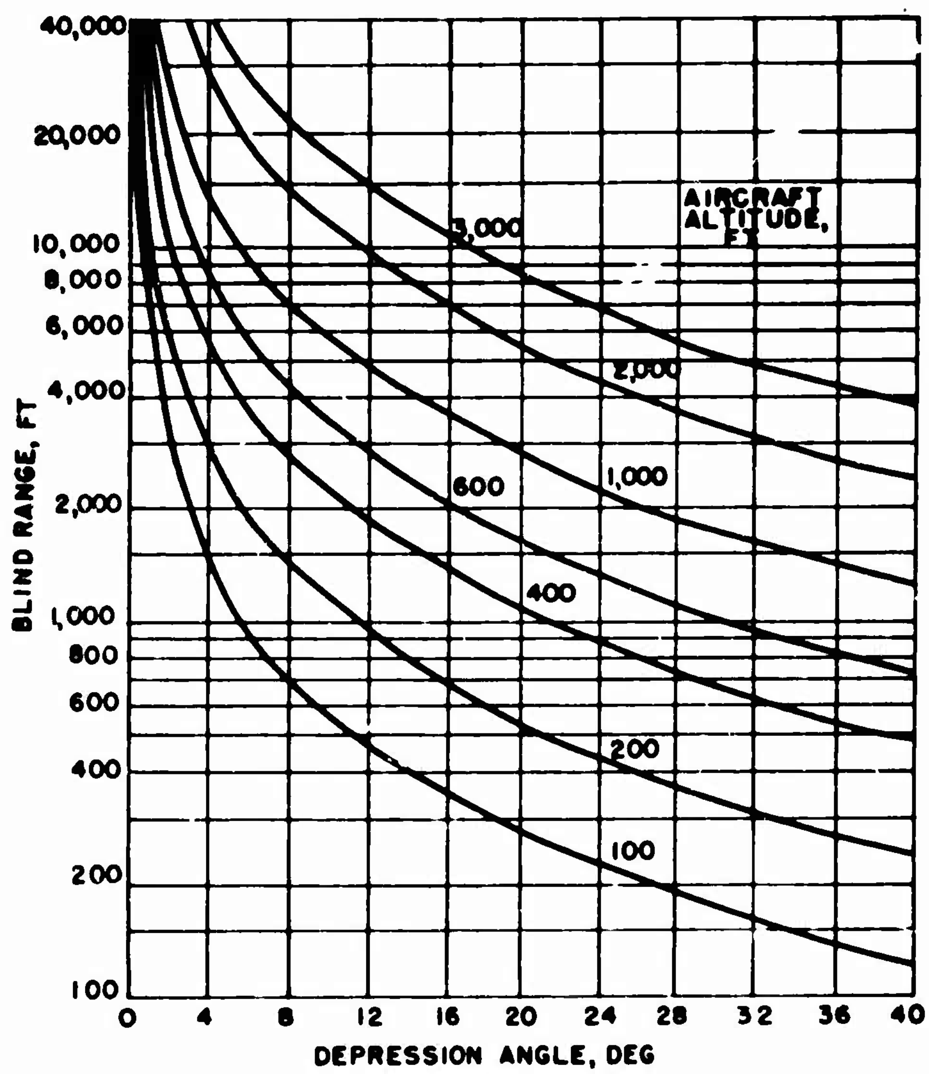


FIG. 3. Blind Range for Various Altitudes and Maximum Depression Angles.

TERRAIN OBSTRUCTION OF VIEW

The degree of obstruction by the terrain has been estimated from contour maps by a graphical method (Ref. 3). The results can be presented in terms of percent of area within view (useful for estimates of reconnaissance effectiveness), or probability that a spot on the terrain at various ranges is within view (useful for weapon-delivery analyses). Figure 4, taken from Ref. 3, shows the average percentage of various types of terrain within view from various altitudes. As the terrain becomes rougher, less of it is within the view of the air observer. However, an inversion of this trend occurs when going from rough to very rough terrain. It is hypothesized that the sides of the hills are less obscured when they are very steep; the associated vertical development leads to greater visibility. Figures 5, 6, and 7 show the probability that a spot on the terrain is within view from aircraft at various altitudes, as a function of ground-range. Since these results do not include the masking effects of foliage, the results are expected to be overestimations of area within view and of probability of seeing a target. This was shown to be true in some cases where the method of obstruction estimation was compared to the results of a field study[1]. These curves can therefore be used to set the upper limits to the measures of obstruction.

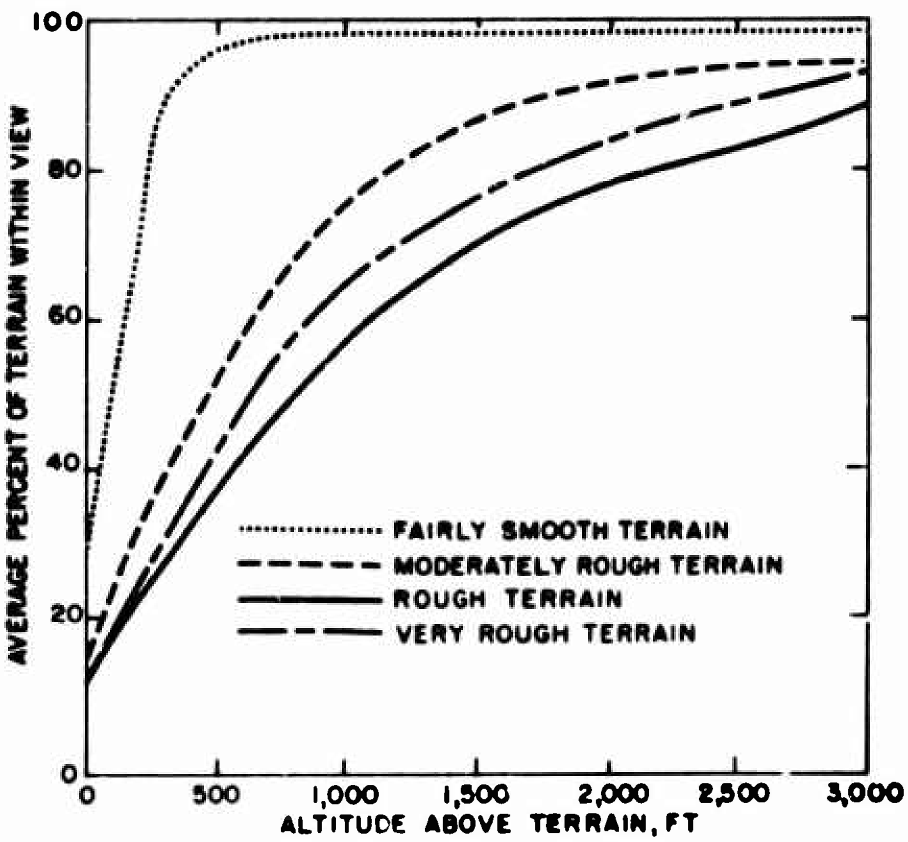


FIG. 4. Percentage of Various Types of Terrain Seen from Aircraft.

[1]U. S. Naval Ordnance Test Station. Terrain Effects Upon Air-to-Ground Target Visibility, by Carol Gill. China Lake, Calif., NOTS, 15 May 1962. (IDP-1487), UNCLASSIFIED.

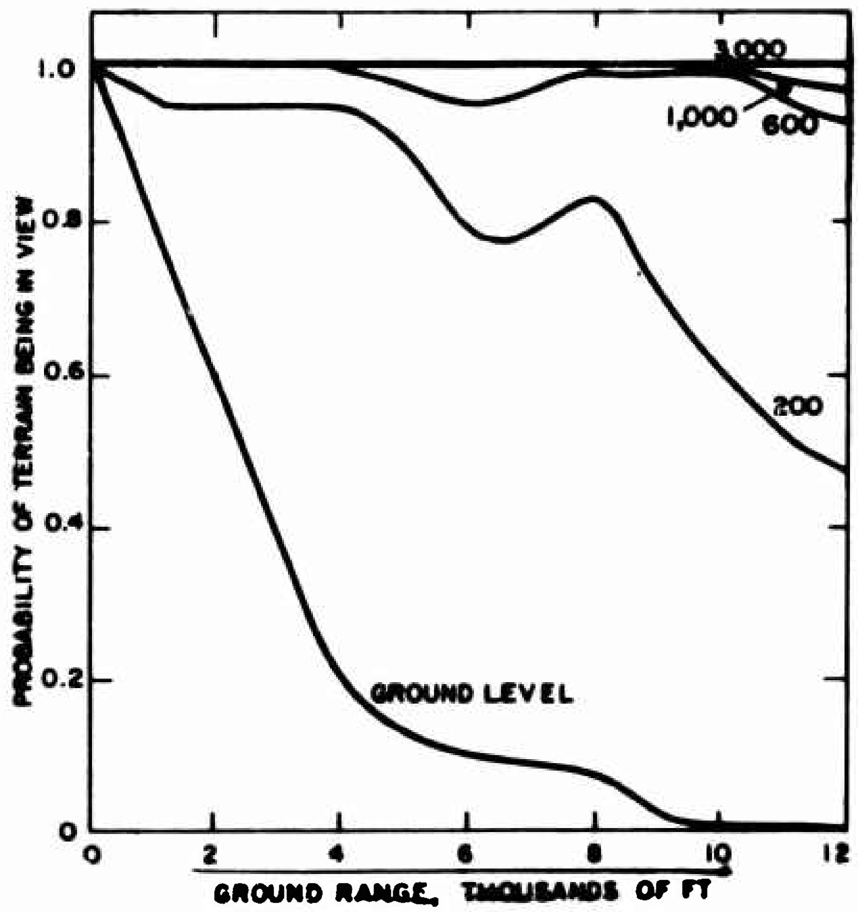


FIG. 5. Probability of Fairly Smooth Terrain Being in View. Aircraft altitude above terrain is shown on curves, in feet.

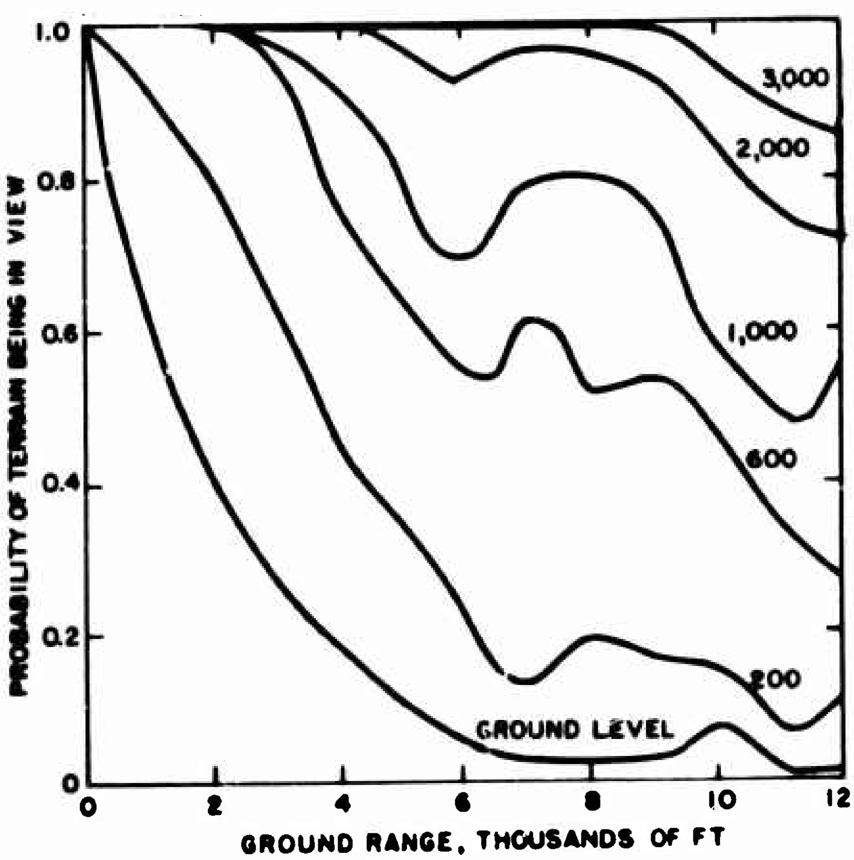


FIG. 6. Probability of Moderately Rough Terrain Being in View. Aircraft altitude above terrain is shown on curves, in feet.

The curves presented in this section can be used to estimate the probability of the target's being in view. Whether the target is detected and identified once within view is another problem which will be discussed in the section on Psychophysics of Air-to-Ground Search.

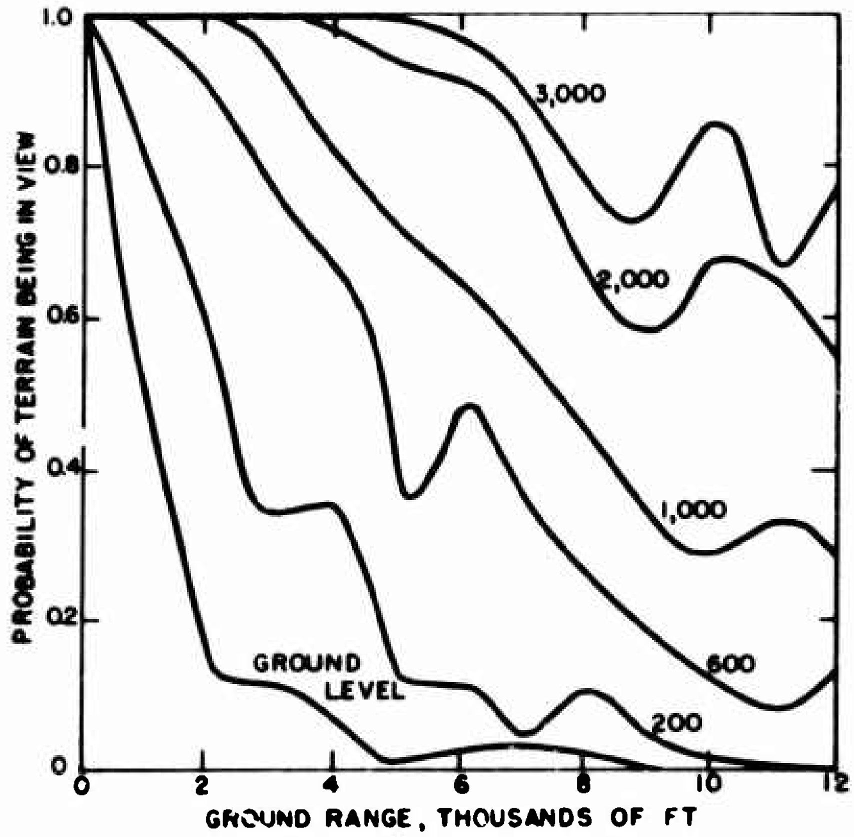


FIG. 7. Probability of Rough Terrain Being in View. Aircraft altitude above terrain is shown on curves, in feet.

KINEMATICS OF AIR-TO-GROUND SEARCH

The motion of the field being searched with respect to the observer can affect, in one way or another, search performance. In some cases, motion might increase performance by causing the observer to employ a more systematic method of search than that used in a static field. However, search time limitation imposed by motion of the field tends to reduce performance, and under some conditions, motion per se of the field being searched will reduce search effectiveness.

ANGULAR RATE OF THE GROUND

An equation giving the angular rate of any ground object within view can be derived from the geometry shown in Fig. 8. The aircraft is diving in the plane ABCD with a dive angle δ at a velocity V. The target, T, is lying in a flat plane beneath the aircraft. Its coordinates, measured with respect to the aircraft, are H, distance beneath the aircraft; R, distance in front of the aircraft; and S, offset distance to the side (perpendicular to ABCD). The angular velocity of the point T can be measured with respect to the velocity vector V. The rate of change of α, the angle between V and AT, is the angular velocity of point T. It is seen that

$$AT = \sqrt{H^2 + R^2 + S^2} \tag{1}$$

$$AE = \frac{R}{\cos \delta} \tag{2}$$

and

$$ET = \sqrt{S^2 + (H - R \tan \delta)^2} \tag{3}$$

Then, by the law of cosines,

$$\cos \alpha = \frac{(R + H \tan \delta) \cos \delta}{\sqrt{H^2 + R^2 + S^2}} \tag{4}$$

Differentiating Eq. 4 with respect to time, one obtains

$$\frac{d\alpha}{dt} = - \frac{(H^2 + R^2 + S^2)\left(\frac{dR}{dt} + \frac{dH}{dt} \tan \delta\right) \cos \delta}{(H^2 + R^2 + S^2)^{3/2} \sin \alpha} +$$

$$+ \frac{(R + H \tan \delta)\left(H \frac{dH}{dt} + R \frac{dR}{dt}\right) \cos \delta}{(H^2 + R^2 + S^2)^{3/2} \sin \alpha} \tag{5}$$

From Eq. 4 one finds that

$$\sin \alpha = \sqrt{\frac{(R \sin \delta - H \cos \delta)^2 + S^2}{H^2 + R^2 + S^2}} \tag{6}$$

One also has the relation:

$$\tan \delta = \frac{\frac{dH}{dt}}{\frac{dR}{dt}} \quad (7)$$

and

$$V = - \frac{\frac{dR}{dt}}{\cos \delta} \quad (8)$$

By substituting Eq. 6, 7, and 8 into Eq. 5 and simplifying the result, one obtains

$$\frac{d\alpha}{dt} = \frac{\sqrt{S^2 + (H \cos \delta - R \sin \delta)^2}}{H^2 + R^2 + S^2} V \quad (9)$$

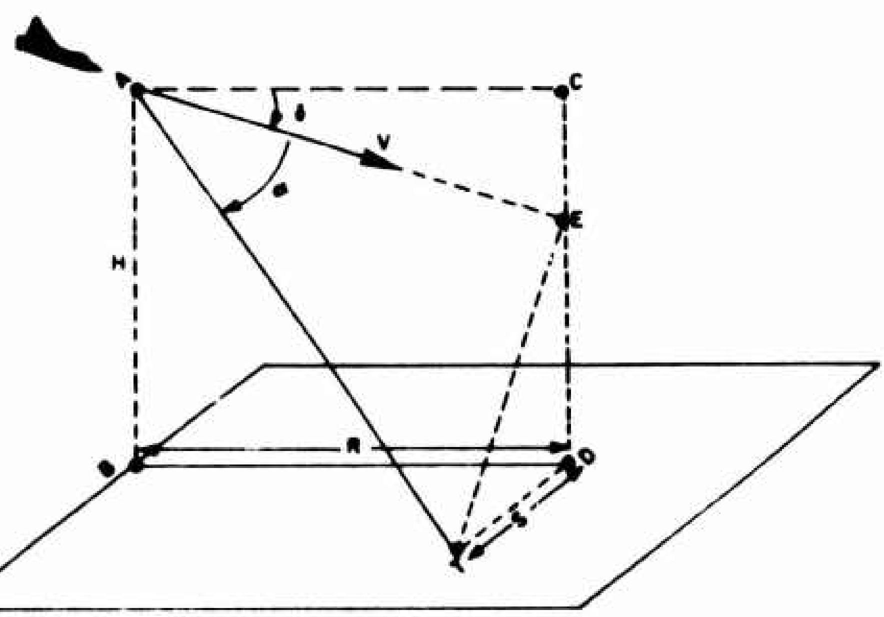


FIG. 8. Angular Velocity Geometry for Air-to-Ground Search. AB, BF, and BD form an orthogonal coordinate system.

Equation 9 can be used to compute the angular velocity of any point on the ground beneath an aircraft diving or flying level with a velocity V. Values of the angular rate encountered in level flight can be taken from the nomograph shown in Fig. 9 for selected ranges of altitude and velocity. Some angular-rate contours for level flight over flat terrain are shown in Fig. 10, 11, and 12. The blind areas shown in the figures are calculated from a maximum depression angle of 16 degrees dead ahead and a maximum depression angle of 32 degrees at an angle 45 degrees back from dead ahead. It can be seen that at the lower altitudes of 50 and 100 feet, fairly high angular rates are encountered beyond the blind range, whereas from a 500-foot altitude the visible part of the terrain dead ahead is moving more slowly with respect to the pilot.

The peculiar shapes of the iso-angular rate curves shown in Fig. 10, 11, and 12 cannot be easily understood by inspection of Eq. 9. Simplifying Eq. 9 to level flight ($\delta = 0$) and differentiating with respect to S, one obtains

$$d\left(\frac{d\alpha}{dt}\right) \quad \frac{[R^2 - (H^2 + S^2)]\,V}{(H^2 + R^2 + S^2)^2\,(S^2 + H^2)^{1/2}}\; S\,dS\ . \qquad (10)$$

It is seen that for all points where $R^2 > (H^2 + S^2)$, an increase in S will cause an increase in the angular rate. When $(H^2 + S^2) > R^2$, the angular rate decreases with increasing S. It can be shown that the effect upon the angular rate of a point on the ground produced by a change in aircraft altitude is given by Eq. 10 when HdH is substituted for SdS. Figure 13 shows the boundary on the ground where this change in sign of $d(d\alpha/dt)$ is found. Data shown in this figure apply only to level flight, although a similar boundary between increasing and decreasing $d\alpha/dt$ can be mapped for aircraft diving or climbing.

EQUIVALENT ANGULAR RATES

The angular rate of a point in the field encountered at some given altitude, velocity, and dive angle can be duplicated by flight at some other altitude, velocity, and dive angle. Such duplication of the angular rate of all the points in the field is not possible, however, Figure 14 shows the angular rate of ground points as seen from two different altitudes and velocities, selected so that at 3,200-foot ground-range dead ahead, the rates are equal. The peripheral field is moving faster at the lower than at the higher altitude. In Fig. 15, rates encountered in level flight are compared to those encountered in a dive. Again, velocity is chosen so that the rates are equal 2,400 feet ahead of the aircraft. Even the peripheral rates are about equal at this range, and at shorter ranges the differences between rates are not large. At about 3,400 feet ahead of the diving aircraft, the angular rate of the ground is zero; at points beyond that, the rate is negative. This is the main difference between dives and level flight. In level flight, the rate has the same sign everywhere and is zero only at infinity. A more detailed analysis of the angular rates encountered in dives, with application to landing aircraft and pilot judgments of motion, is given in Ref. 4.

Figures 14 and 15 illustrate the differences in angular rates and hence, a possible source of error introduced in extrapolating search data from one flight condition to another. Such an error would be due to changes in the performance of human searchers that is induced by the different motions in the field being searched.

INSTRUCTIONS FOR USE OF NOMOGRAPH

Given: (1) S offset distance to target
(2) H aircraft altitude
(3) R range ahead to target
(4) V velocity of aircraft

Desired: $\frac{d\alpha}{dt}$, the angular rate of a point on the ground at (R, S)

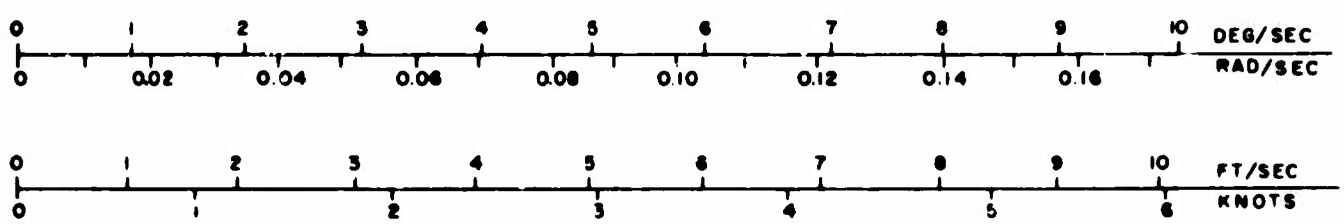
EXAMPLE

S = 265 feet
H = 200 feet
R = 2,000 feet
V = 1,000 ft/sec

Procedure:

(1) Find the desired S (265 ft) on the S-scale on the upper left of the nomograph.
(2) Then go across horizontally until the desired H-curve (200 ft) is intersected.
(3) Go <u>straight down</u> from this intersection to the index line V-W.
(4) Follow the curved lines down until the desired vertical range line (2,000 ft) is intersected.
(5) Draw a line from the index point on the lower right, through the intersection point obtained in (4), up to the index line X-Y.
(6) Now draw a line from this intersection point on the index line, through the desired velocity (1,000 ft/sec), across to the angular rate scale on the far left. The answer (4.67 deg/sec) is obtained on this scale.
(7) For convenience, two different scales, A and B, can be used. In the example mentioned, the A velocity scale is used, so the angular rate must be taken off the A dα/dt scale. If the B scale had been used (V = 200 ft/sec) the corresponding angular rate would be 0.93 deg/sec, taken off the B scale.

Scales are given below for conversion from ft/sec to knots and from deg/sec to radians/sec.



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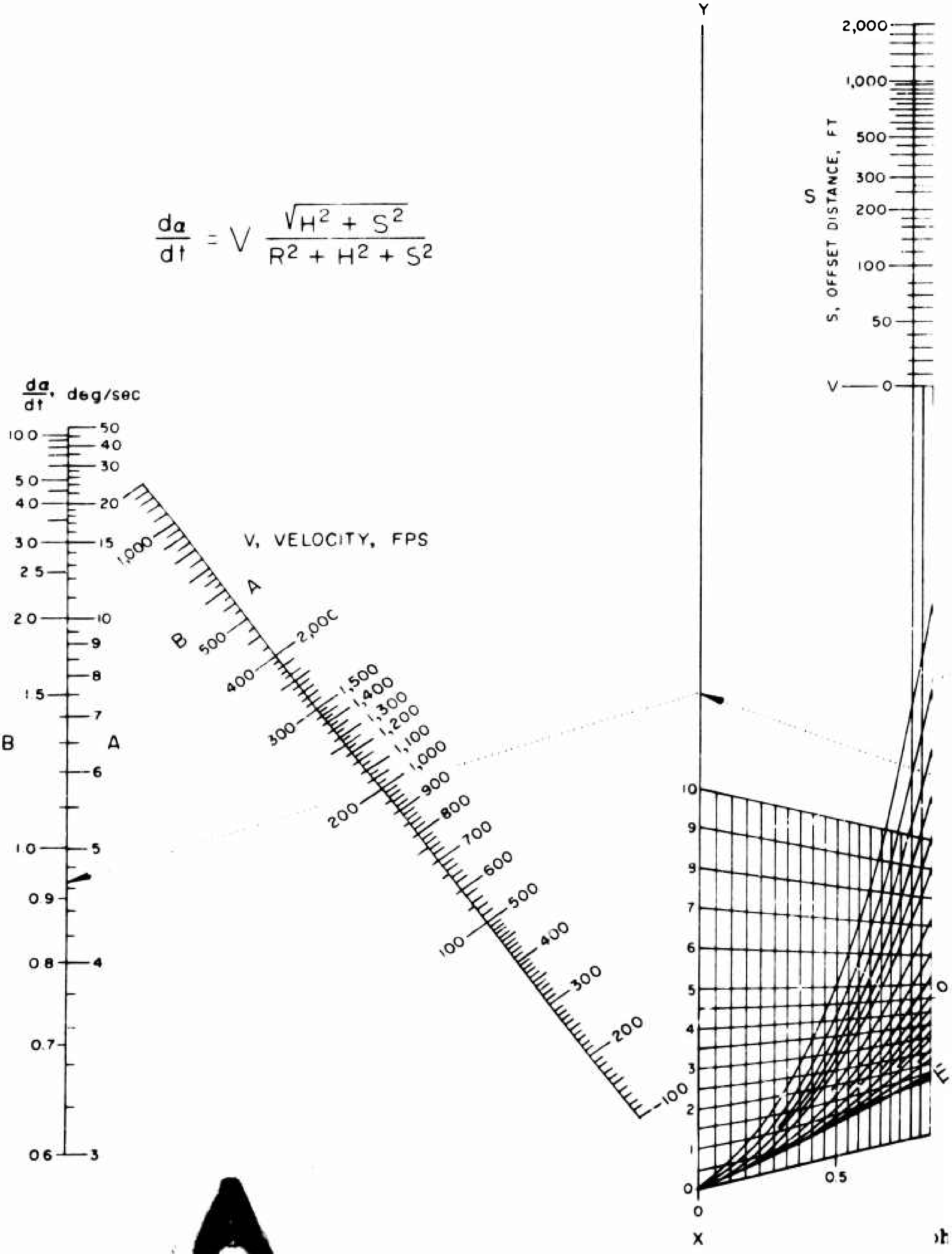
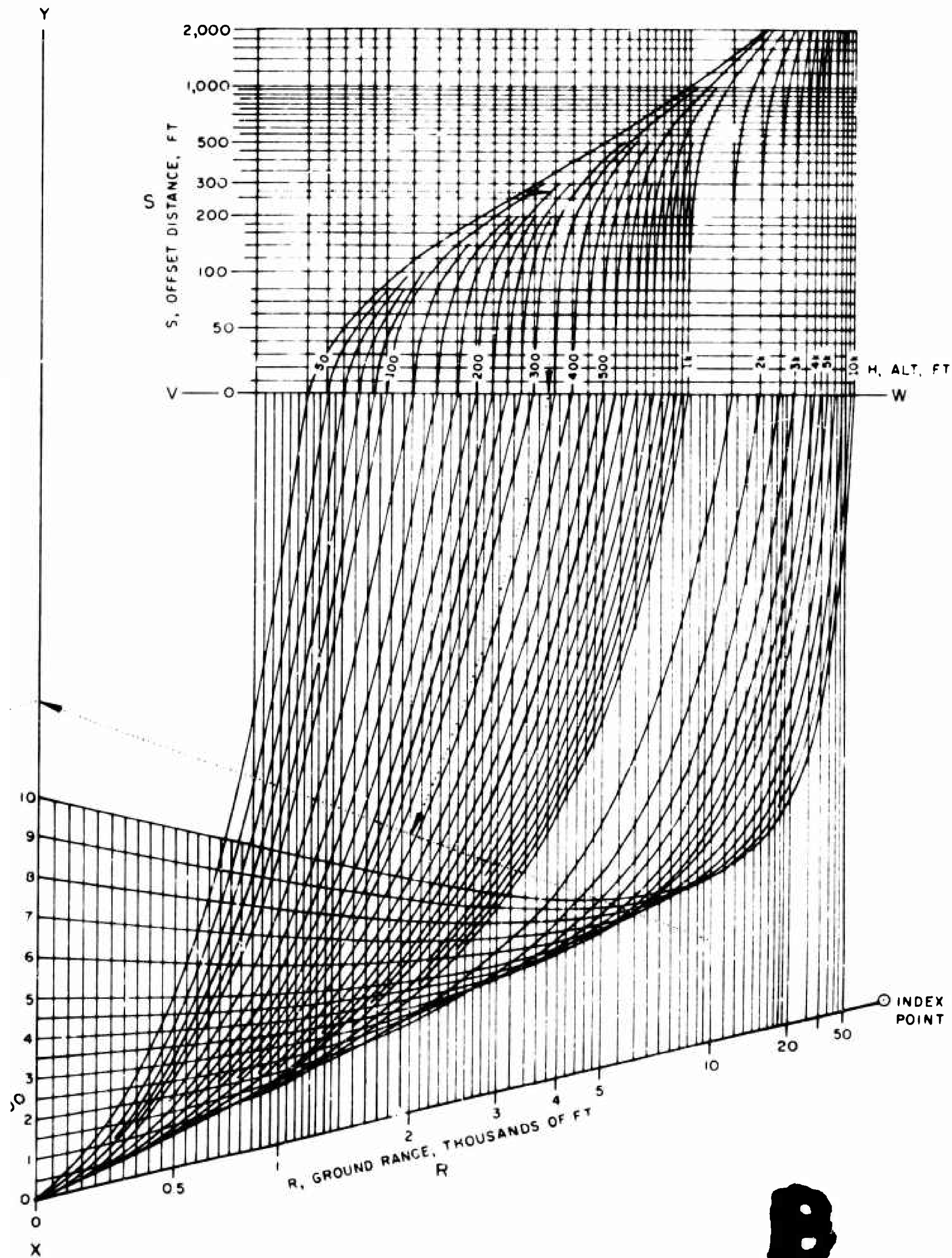


FIG. 9. Nomograph for Computing Angular



'or Computing Angular Rate in Level Flight.

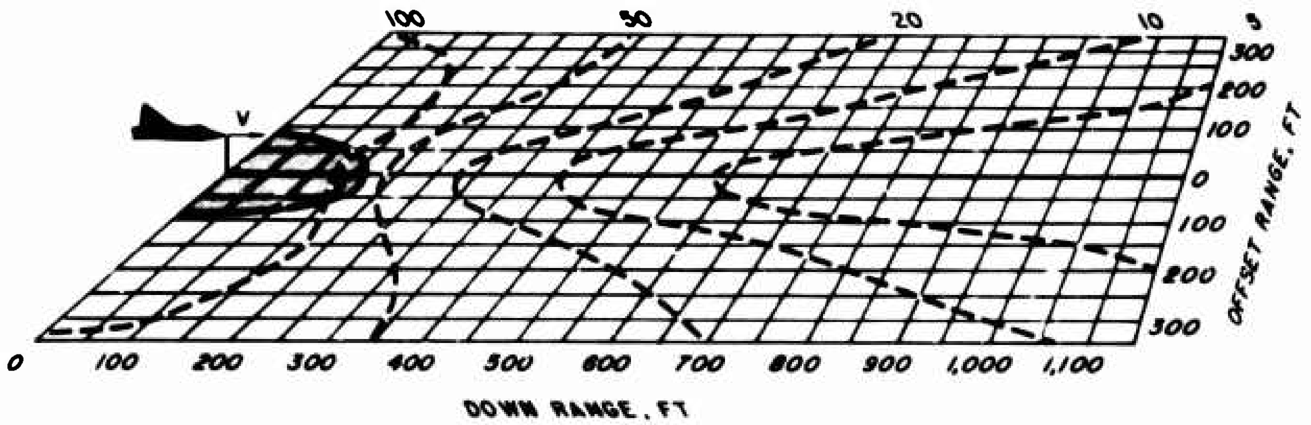


FIG. 10. Angular-Rate Contours of Terrain as Seen by Pilot During Level Flight at 50-Foot Altitude and 350-Knots Velocity. Angular rate is given on the contours in deg/sec. Blind area is also shown (darker portion).

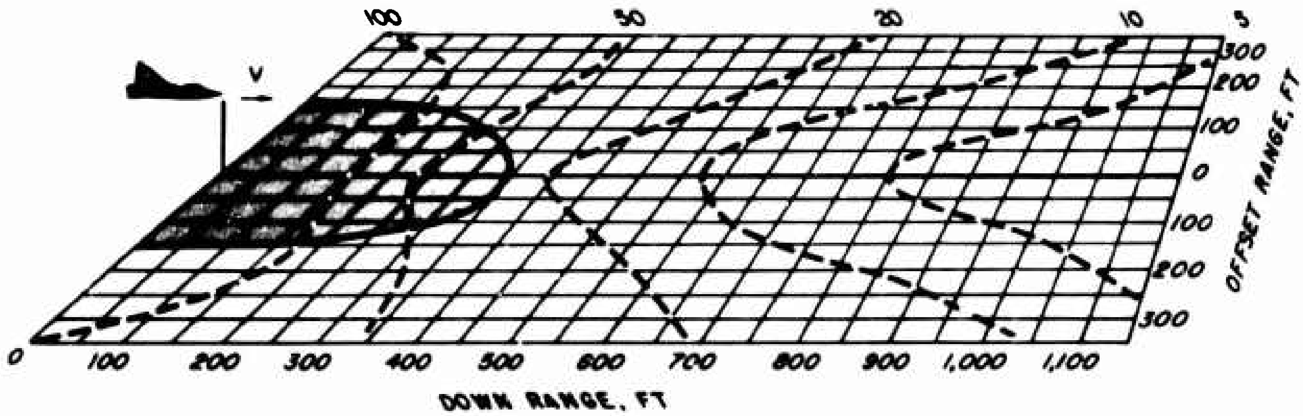


FIG. 11. Angular-Rate Contours of Terrain as Seen by Pilot During Level Flight at 100-Foot Altitude and 350-Knots Velocity. Angular rate is given on the contours in deg/sec.

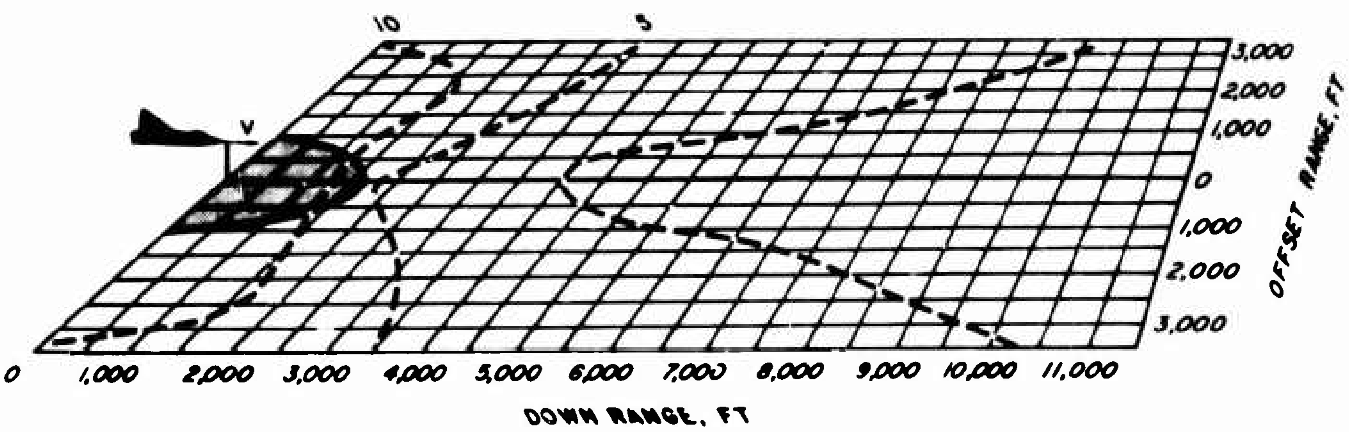


FIG. 12. Angular-Rate Contours of Terrain as Seen by Pilot During Level Flight at 500-Foot Altitude and 350-Knots Velocity. Angular rate is given on the contours in deg/sec.

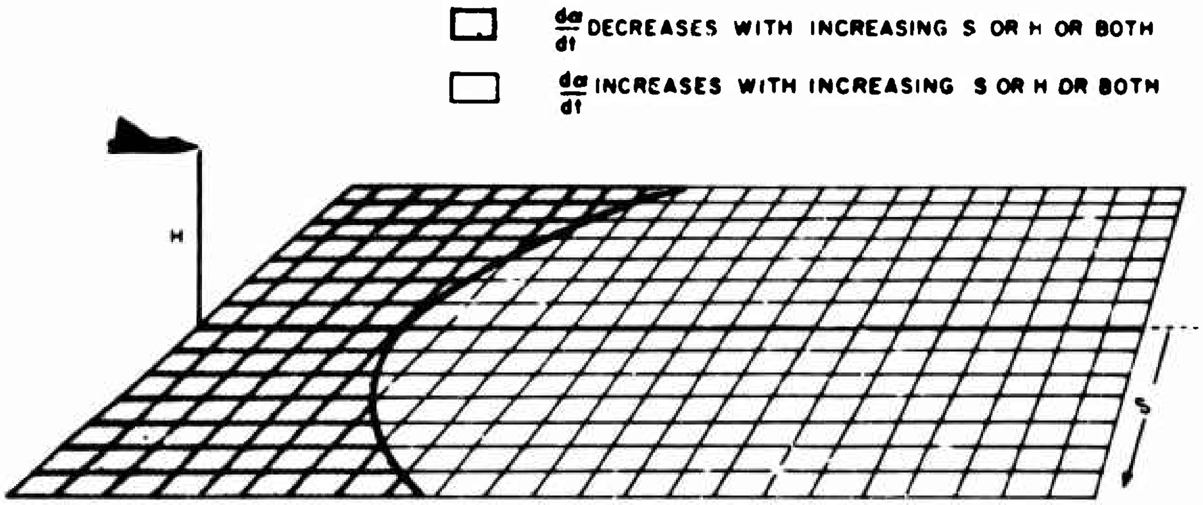


FIG. 13. Boundary Between Increasing and Decreasing Angular Rate as S or H Increases. Aircraft is in level flight.

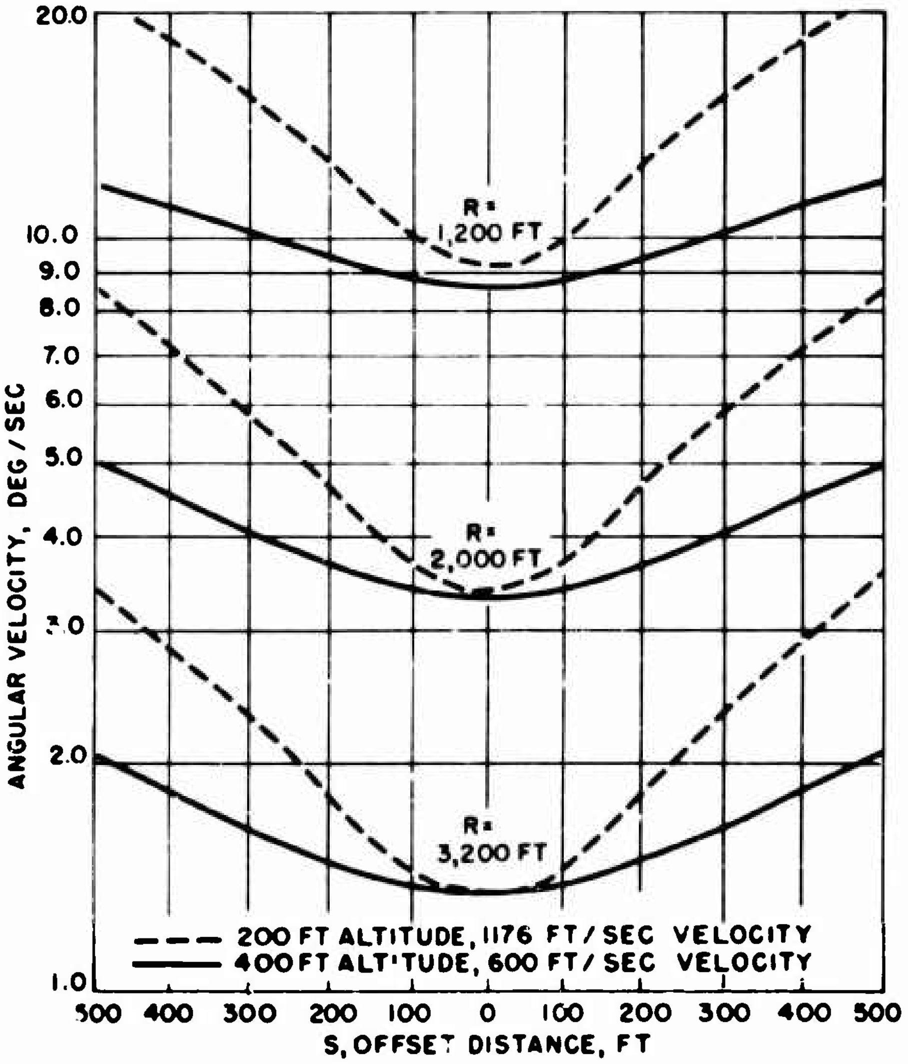


FIG. 14. Angular Velocity of Ground Points as Seen From an Aircraft in Level Flight. Range to target is shown on the curves. (See Fig. 8.)

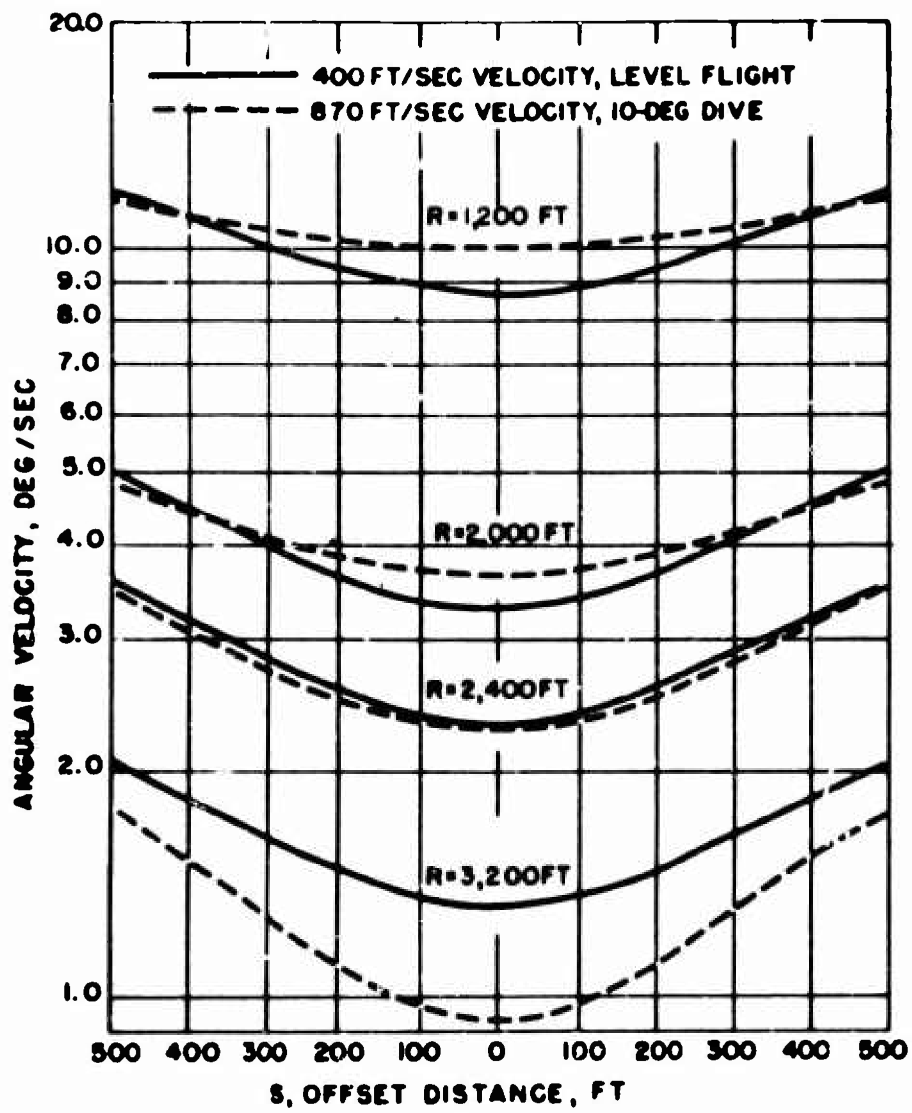


FIG. 15. Angular Velocity of Ground Points as Seen from Aircraft at 600-Foot Altitude.

TARGET ANGULAR RATE

Thus far, the discussion has treated the angular rate of part of the visual field and is applicable to search considerations. Once a target has been detected during this search, the next step may be to make a pass over it and release or fire a weapon. It is therefore advisable to consider the angular rate of a target as the aircraft flies over it. When diving toward the target or flying at high altitudes, the target's angular velocity is low (at or before weapon release) and has small effect upon search effectiveness and tracking accuracy.

Since during level flight at low altitudes the velocity effect could be a major one, curves are shown only for low altitudes and higher velocities. The target angular rates are shown in Fig. 16 through 1° as a function of aircraft altitude, range to target, and time to target. The release points of a weapon in a vacuum and of a high-drag bomb are also shown on the curves and will be referred to later. It is interesting to note for the cases shown that the angular rate of the target is fairly low and does not change rapidly at ranges over 5,000 feet. At ranges under 5,000 feet, when the aircraft is getting close to the target, the angular rate begins to increase rapidly. There may therefore be greater errors when tracking during low-level fast flights than during other weapon delivery modes. The angular rates described here, incidentally, are the same as those encountered by the ground observer attempting to track an aircraft.

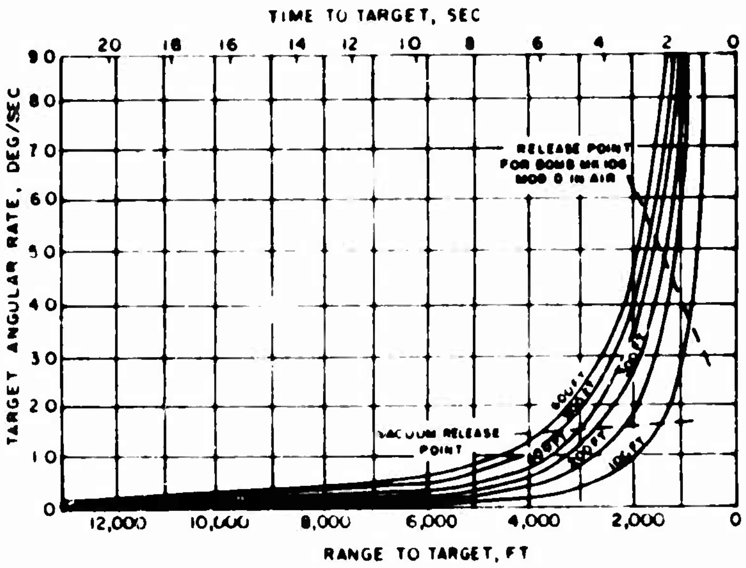


FIG. 16. Target Angular Rate With Aircraft Velocity at 350 Knots in Level Flight. Altitudes are shown on curves.

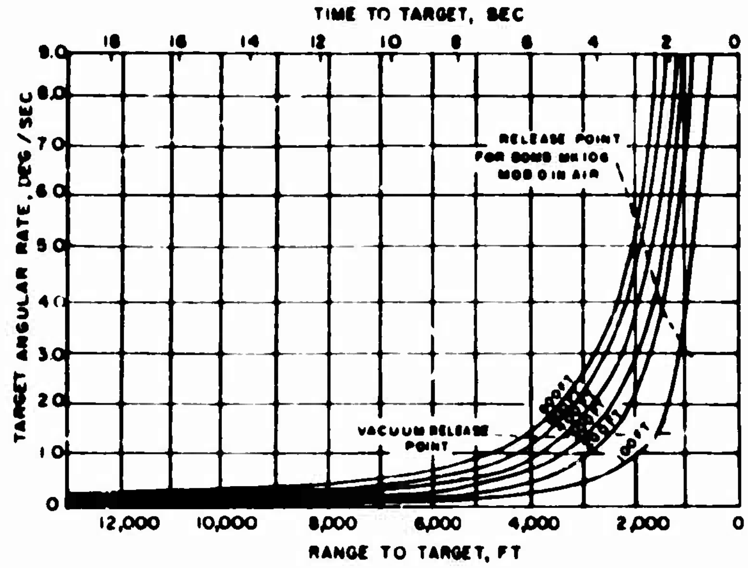


FIG.17. Target Angular Rate With Aircraft Velocity at 400 Knots in Level Flight. Altitudes are shown on curves.

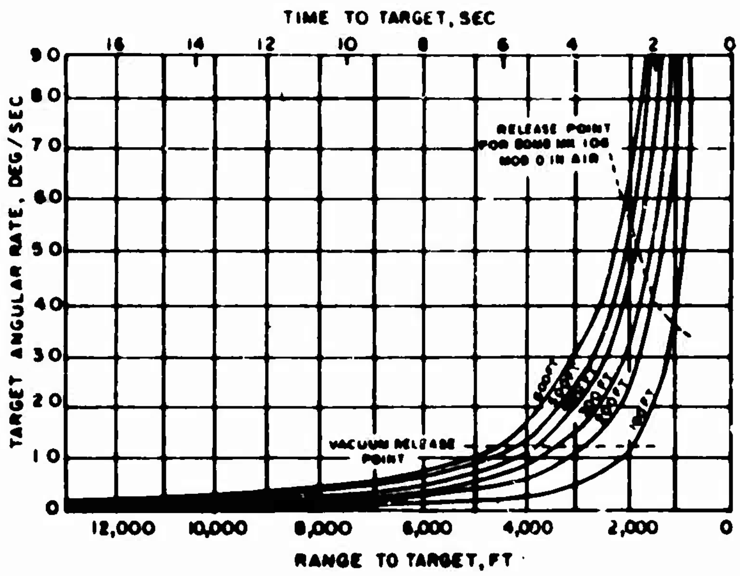


FIG. 18. Target Angular Rate With Aircraft Velocity at 450 Knots in Level Flight. Altitudes are shown on the curves.

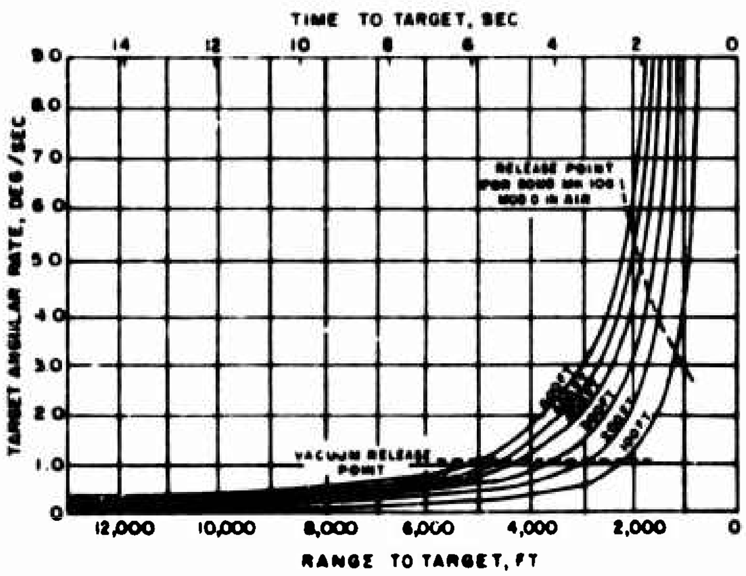


FIG. 19. Target Angular Rate With Aircraft Velocity at 500 Knots in Level Flight. Altitudes are shown on the curves.

MOVING TARGETS

It has been assumed in the preceding discussion that the target is stationary with respect to the ground. Motion of the target can enhance detection in three ways: (1) a new target is created by the motion, such as the wake of a ship or a dust cloud behind a tank; (2) the change in location of the target due to its motion is noted; and (3) in some cases, the motion per se of the target attracts the observer's eyes. Although the last two factors are difficult to assess, a consideration of theory and experiment will illustrate their relevance.

Consider two objects moving parallel through the visual field with angular velocities ω_1 and ω_2. A differential threshold for angular velocity may be defined as

$$\Delta\omega = \omega_1 - \omega_2 \tag{11}$$

That is, the difference between the angular velocities of the two objects must be at least $\Delta\omega$ or an observer cannot with any confidence tell that there is a difference.

Laboratory measurements of $\Delta\omega$ have been made with moving spots on an oscilloscope, rotating disks, needle pointers, and other such devices. It has been found that $\Delta\omega$ is a function of the angular velocity of the reference object such that

$$W = \frac{\Delta\omega}{\omega} = \text{constant} \quad (\omega \neq 0) \tag{12}$$

within certain limits. W is known as the Weber ratio. From data summarized in Ref. 5 (Fig. 20), it is seen that W = 0.14 for curve 1 and W = 0.08 for curve 2.

Consider the simple case of a moving target being viewed from an aircraft flying level with constant velocity. If the target is moving along the ground track of the aircraft, its angular velocity would be

$$\omega_t = - \frac{(V - v)H}{H^2 + R^2} \tag{13}$$

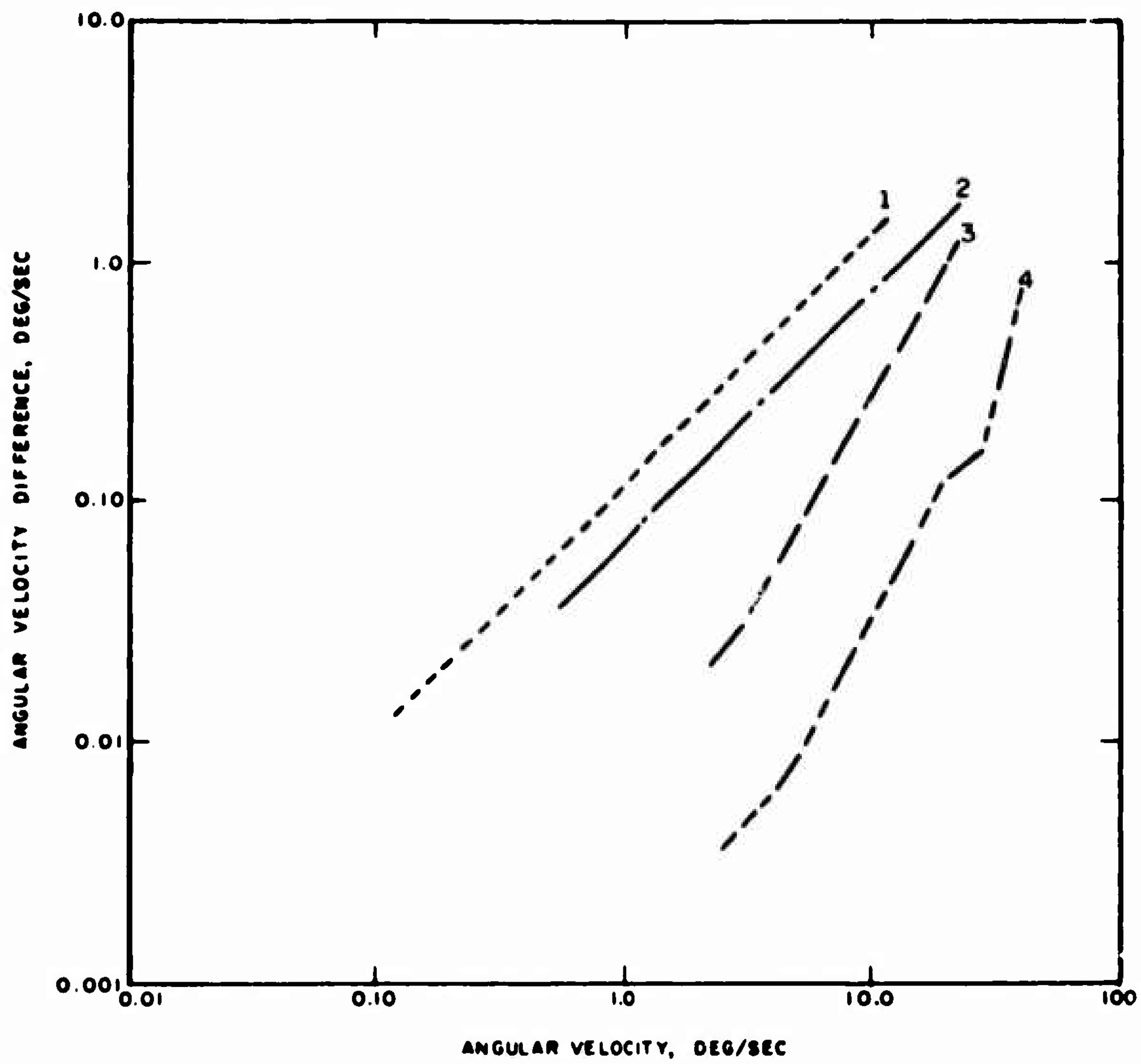
as compared to the angular velocity of points on the ground about the target, which is given by

$$\omega_g = - \frac{HV}{H^2 + R^2} \tag{14}$$

where v is the velocity of the target and the other symbols have been defined earlier. It can be shown that

$$W = \frac{v}{V} \tag{15}$$

If a Weber ratio could be determined for the above situation and were found to be 0.10, say, it could be concluded that targets moving less than one-tenth the aircraft's velocity would not be spotted by virtue of their motion per se.



1. Adjacent stimuli 3. Superimposed stimuli, 3.6 deg field
2. Separate stimuli 4. Superimposed stimuli, 15.0 deg field

FIG. 20. Velocity Discrimination Thresholds.

OPERATIONAL EFFECTS

It should be pointed out that two additional factors must be considered in some cases when applying the angular rate information presented here. The angular rates are measured with respect to the aircraft's ground velocity vector, and in the presence of crosswind, the velocity vector and the aircraft reference line are not coincidental. Also, since it is not always necessary to keep the eyes directed along the velocity vector, the searching pilot can greatly reduce the angular rates simply by tracking the target with head and eye movements. The same results could be obtained with a properly designed search or bombing system.

OPTICAL ASPECTS OF AIR-TO-GROUND SEARCH

Detection involves light entering and passing through the atmosphere, reflecting off the target and its surroundings, and again passing through the atmosphere to be received by the eye or a sensor. The amount, spectrum, and direction of the emitted light, the optical properties of the atmosphere, and the reflectance of the target and its surroundings affect target detection probability and target detection ranges.

CLOUDS

Clouds have two general effects upon target visibility: obstruction of the target, and diffusion of the light coming from the sun, thus affecting the way the target is illuminated. In some operation analyses, an estimate of the amount of cloud cover is useful. Such data can be found in Ref. 6 through 9. These references give average monthly values of cloud cover and are averaged into seasonal values in Ref. 10. Similar information can be obtained from Ref. 11, 12, and 13.

Illumination, in foot-candles, falling on a fully exposed horizontal plane at any point on the earth at any hour of the day or night, can be found from the charts presented in Ref. 14. In this reference it is stated that when the sun is obstructed by thin clouds, the value of illumination should be divided by two: for average cloud conditions obstructing the sun's rays, the values given for clear days should be divided by three; and for dark stratus clouds, the values should be divided by ten.

In some mathematical expressions for visibility parameters, the brightness of the sky or the ratio of the brightness of the sky to the brightness of the target background appears. Such data can be found in Table 5.2 of Ref. 15, Table 3 of Ref. 16, and Table C of Ref. 17.

In experiments concerning visual resolution, it was found that resolution will increase appreciably as skies approach overcast conditions (Ref. 18). The cloud cover reduces the effects of "shimmer" (see next section).

ATMOSPHERIC ATTENUATION

Light passing through the atmosphere is subject to absorption and scattering; this reduction in intensity of a beam, called attenuation or extinction, has been measured under a variety of conditions. The attenuation coefficient, α, is defined by

$$I = I_o e^{-\alpha x} \qquad (16)$$

where I_o and I are the intensities of a collimated beam of light entering and emerging from a layer of air x-units thick. Values for α can be found or calculated from data given in Ref. 15 through 21 and generally range from 0.05 to 0.5 per kilometer. Such information can be used in calculations of target-background contrast attenuation for application in visibility models used to compute detection and recognition ranges. Light scattering of particles in the atmosphere results in a luminance of the "space" between the observer and the target. This path luminance acts to reduce target-background contrast and hence make the target more difficult to find.

The irregular refraction by the atmosphere of the light rays reflected by an object frequently makes identification of the object difficult. The index of refraction of the air sometimes varies rapidly and irregularly from place to place, causing shimmer (Ref. 15, 18, 22 and 23). An example of the degradation in visual resolution caused by shimmer is shown in Fig. 21 (taken from Ref. 22). Such degradation can be assumed for some conditions in recognition range calculations.

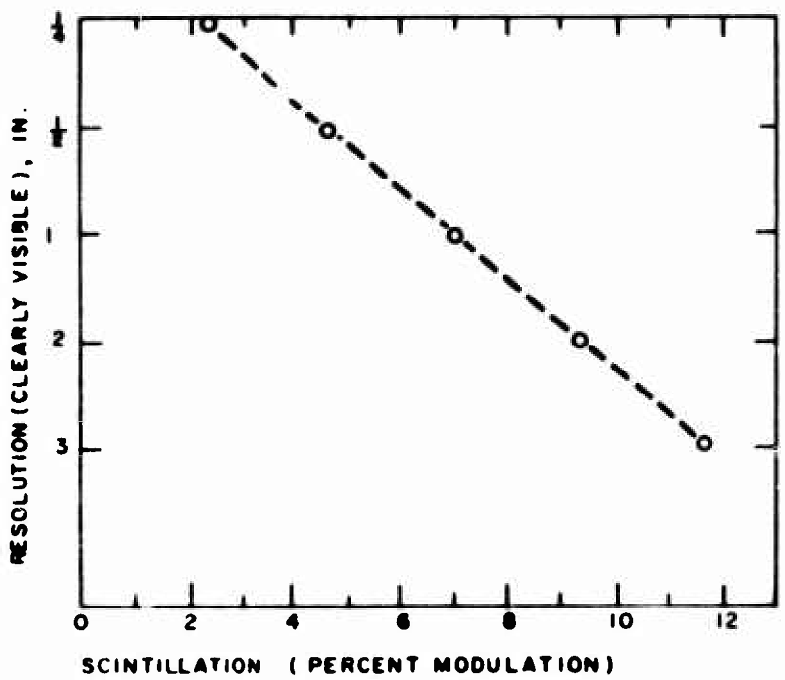


FIG. 21. Degree of Scintillation Versus Resolution Using Landolt Broken-Ring Chart.

TERRAIN AND TARGET REFLECTANCE

One of the factors that determines whether a target can be detected is the contrast in brightness and color between the target and its background. A very broad classification of backgrounds by color is given in Ref. 24. The role of color is indicated in Fig. 22, where the eye's sensitivity, the intensity of sunlight, and the reflectance factor of a red surface are shown as functions of wavelength. Reflectance data for various types of terrain are given in Ref. 25, 26, and 27. Figure 23a, taken from Ref. 27, shows the reflectance of various types of desert terrain. Figure 23b shows that the sun's angle makes a considerable difference in the reflectance, and hence brightness, of terrain. The data of Ref. 25 have been converted to a single reflectance factor by using values weighted according to the relative sensitivity of the human eye to different wavelengths. These values are shown in Table 1 as taken from Ref. 28, page 10.

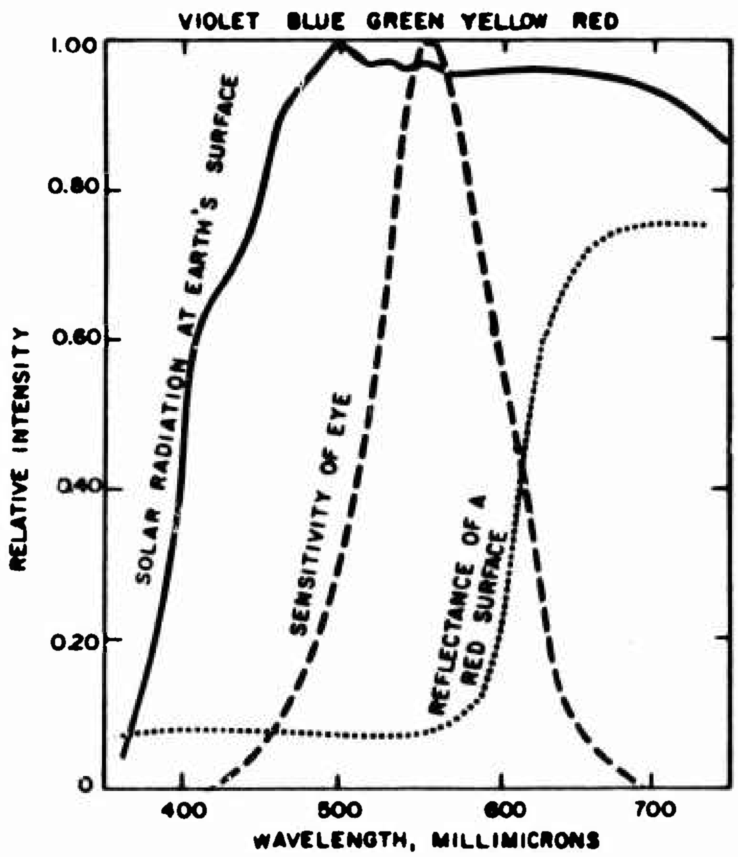


FIG. 22. Eye Sensitivity, Solar Radiation, and Reflectance of a Red Surface.

The reflectance of typical ground targets has not been found in the literature. A single value for reflectance does not exist in most cases: each man, vehicle, or bridge has a number of different reflectances. Some examples of average contrast of a target against a background are available however. (Contrast is defined in the next section.) From measurements on models reported in Ref. 29 it was found that olive drab troops and vehicles in California desert have a contrast of about 0.6. Olive drab troops and vehicles on black pavement, some dirt roads, and green grassy fields, have a contrast of about 0.3.

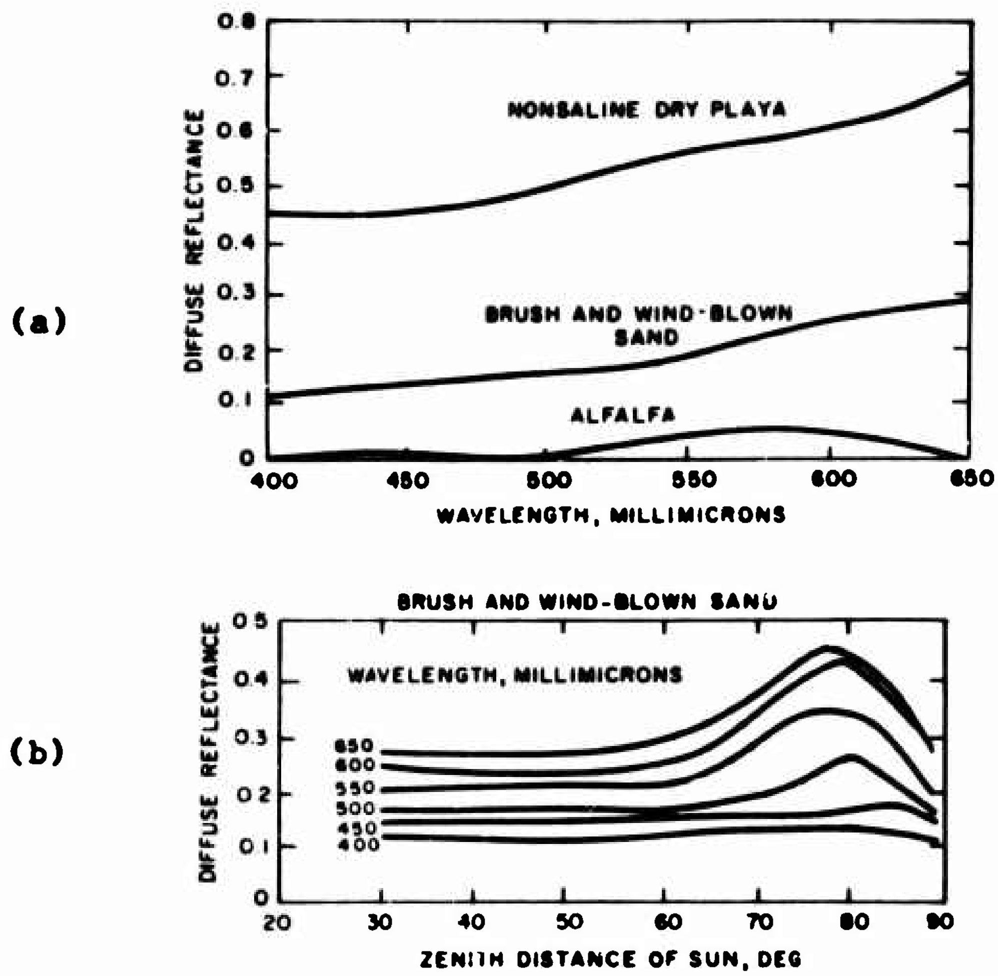


FIG. 23. Reflectance of Desert Terrain.

TABLE 1. Reflectance Factors for Various Surfaces

Surface	Weighted reflectance factor
Black earth	0.03
Earth roads	0.03
Paved roads	0.09
Buildings	0.09
Forest (winter)	0.03
Forest (autumn)	0.16
Forest (summer)	0.10
Grass fields	0.08
Dry meadows	0.08
Lush grass	0.10
Fresh snow	0.77
Open sea	0.50

PSYCHOPHYSICS OF AIR-TO-GROUND SEARCH

The final step in the visual detection process is the reception of light rays from the environment by the observer, and the selection and interpretation of enough pertinent information to permit target detection. The physiological and psychological characteristics of the human visual system are therefore important factors in the estimation of detection ranges and probabilities of detection. Several experiments that have been made in the laboratory and are described briefly below furnish data on visual capabilities.

THRESHOLD CONTRASTS

The brightness of a target and its background can be calculated from illumination and reflectance information or can be measured directly. The contrast of the target is defined as

$$C = \frac{B_t - B_b}{B_b} \tag{17}$$

where B_t is the brightness of the target and B_b is the brightness of the background. For targets darker than their backgrounds the contrast is negative, but since it has been shown that targets are equally visible if their contrasts are numerically equal, the sign need not be regarded as so important. It must be noted that contrast due to color differences is not included in Eq. 17. Color contrast is more difficult to access analytically, and the absence of large color differences in military situations (tanks are seldom painted blue) has led to little investigation of this factor.

In experiments conducted during World War II, threshold (or liminal) contrasts of human observers were determined for various target sizes and adaptation brightness. Liminal contrast is simply defined as that value at which detection occurs 50% of the time. A spot of light was projected onto a white screen located 60 feet from the observer who indicated where the spot appeared. A large amount of data were analyzed and plotted as shown in Fig. 24 that was taken from Ref. 30.

A later experiment by Blackwell and Moldauer (Ref. 31) determined the threshold for various positions of the target on the retina. Targets subtending 1 minute of arc to the observer and presented for 0.01 second were used.

The data of Blackwell reported in Ref. 30 have been extended by Taylor in Ref. 32 and 33. Experiments similar to those described in Ref. 31, but thought more useful in visual search calculations, are reported in Ref. 32. The targets were exposed for 0.33 second instead of the 0.01 second in Blackwell's experiment.

Visual contrast thresholds were determined in Ref. 35 in a manner differing from Blackwell's and Taylor's: Landolt rings were used as targets (Fig. 25). The thresholds were consistently larger than those found by Blackwell.

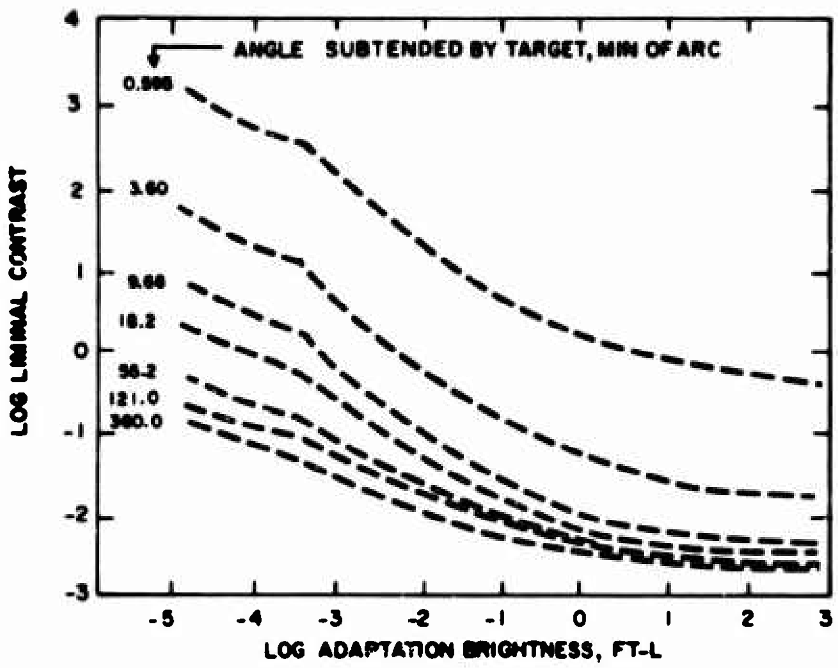


FIG. 24. Liminal Contrasts for Round Targets Brighter Than Their Backgrounds. The target was presented in only one position for a sufficient time to attain maximum frequency of correct response. The liminal contrasts are for 50% correct identification (above chance).

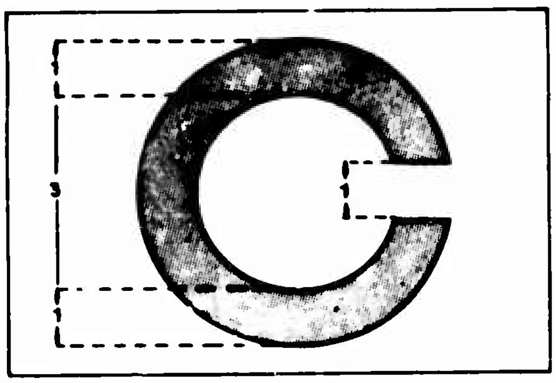


FIG. 25. Landolt Ring, Showing Proportions.

Contrast thresholds were measured for rectangles with length-width ratios of 2 to 200 in a study described in Ref. 36. For target areas less than 100 square minutes, square targets had lower thresholds than rectangular ones: the greater the ratio of length to width, the higher the threshold (Fig. 26). The data are further analyzed in Ref. 37 from which

Fig. 27 was obtained. It is seen that for 100% detection the contrast must be about two times the threshold contrast. The detection probability may be even lower than that shown in Fig. 27. According to Ref. 16, page 94, "the probability of an observer voluntarily reporting the presence of a liminally visible target is nearly zero". Threshold contrasts have also been found for other forms. Crosses, for example, were used in an experiment described in Ref. 38.

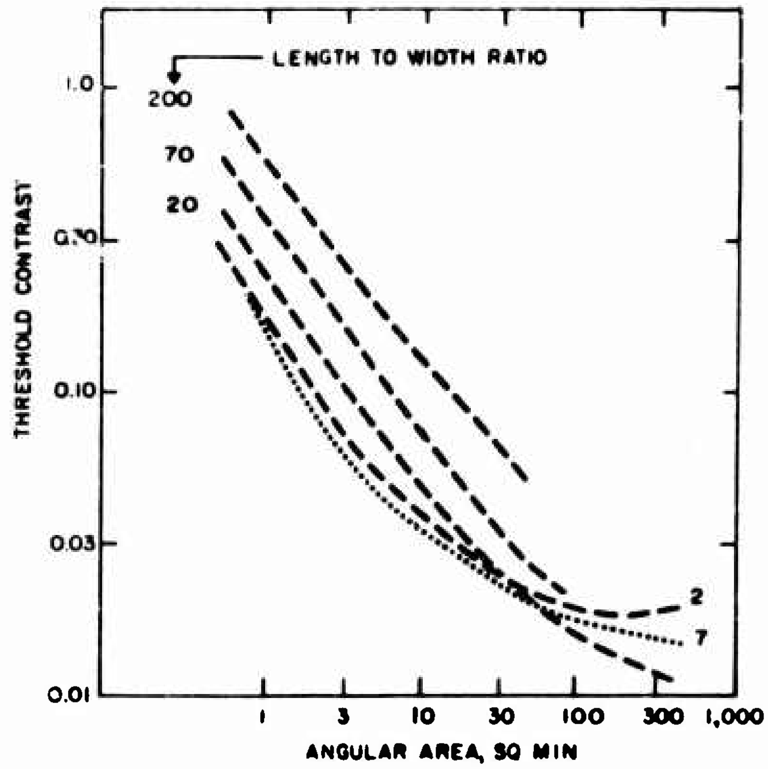


FIG. 26. Threshold Contrasts for Rectangles of Various Dimensions. A 3-second monocular exposure was used with a brightness of 2,950 foot-lamberts.

In the above studies, backgrounds of uniform luminance were used. In a study reported by Bixel and Blackwell (Ref. 39), threshold contrasts were found for circular targets as viewed against a background made up of ball bearings painted gray. A "regular pattern of luminance nonuniformity" was produced. It was found that when the contrast of the target was expressed with respect to the brightness of the immediately adjacent area and not with respect to the average brightness of the whole background, the results were the same as those obtained with the uniform background. "This implies that visibility thresholds are determined by target contrast at target borders rather than by some kind of average contrast."

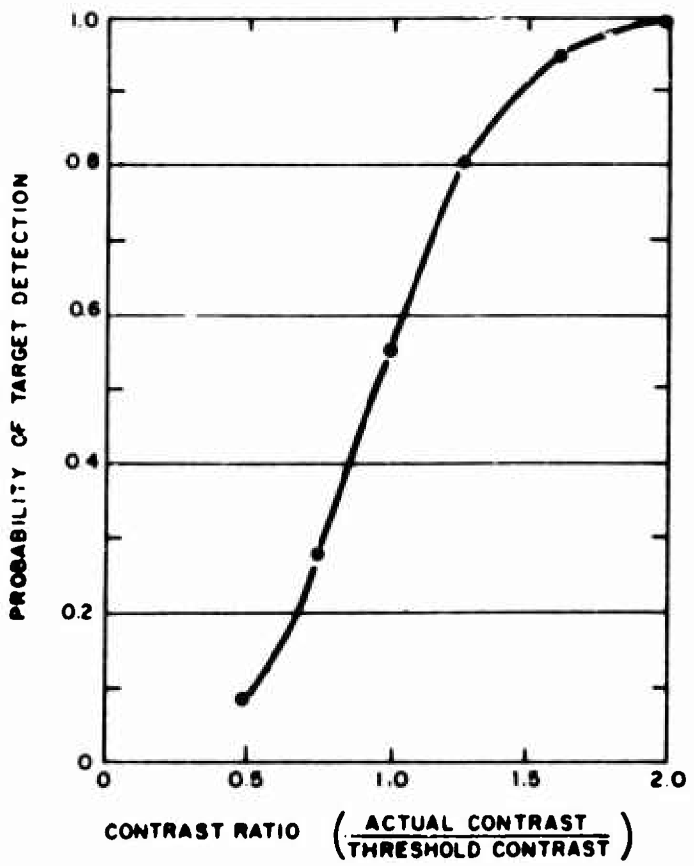


FIG. 27. Average Probability of Detecting Rectangular Targets Against a White Background.

STATIC SEARCH

The experiments described above included very little, if any searching for targets, and it was not necessary to discriminate target from nontarget objects. In searching for ground targets from aircraft, however, it is often necessary to search over a fairly large area, and to make judgments on a number of objects. A number of laboratory experiments have been carried out requiring this kind of search.

In the study of Boynton and Bush, observers were asked to search for a specified target located among a number of irrelevant forms (Ref. 40). The target and objects were located on a circular, back-illuminated glass plate as shown in Fig. 28. Typical results are shown in Fig. 29, taken from Ref. 41 and 42. Performance decreases as search time decreases, and as the number of objects in the display increases.

In the study described in Ref. 43, observers were asked to search a circular field for a target (see Fig. 30) located among a number of similar objects. Search time increased with search area size (see Fig. 31). Since

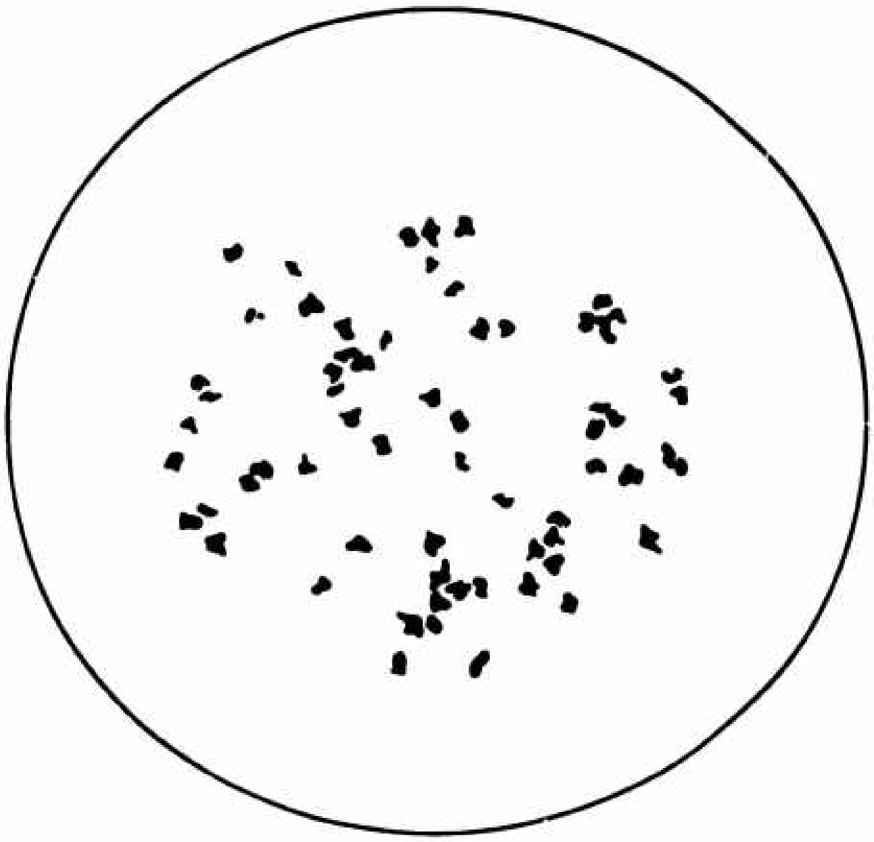


FIG. 28. Example of Field to be Searched, From Experiments of Boynton and Bush (Ref. 40).

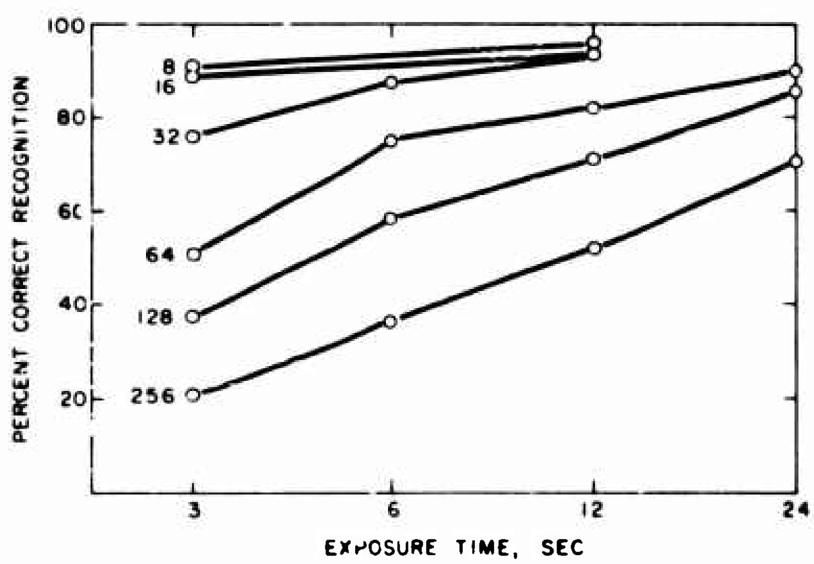


FIG. 29. Search Performance, From Experiments of Boynton and Bush. Object density is shown on each curve.

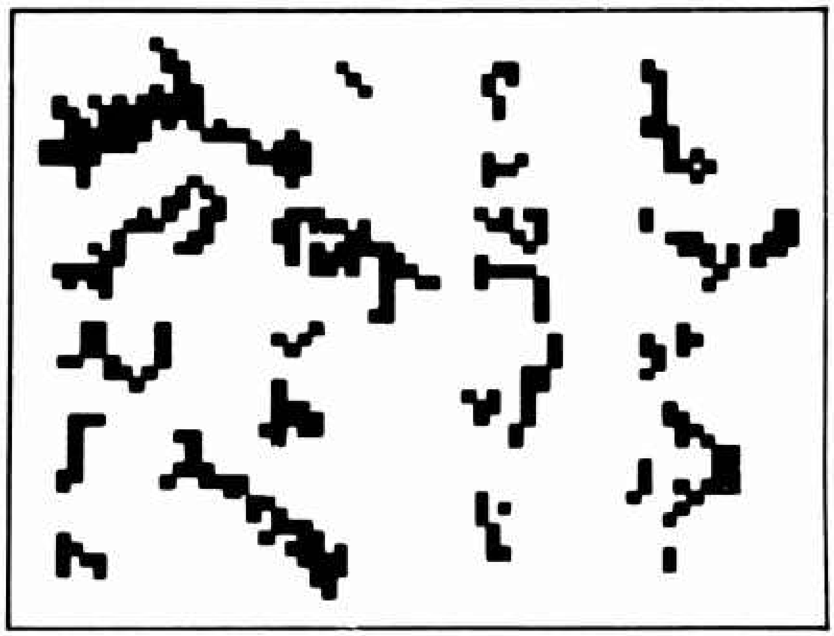


FIG. 30. Targets Used in Experiments by Baker, Morris, and Steedman (Ref. 43). The figure above is not representative of the displays used, but only of the objects in the displays.

the number of forms on a search area was rougly proportional to the search area size, it was felt that the primary factor in the increase in search time was the increase in the number of irrelevant forms.

In one experiment a square white field was partitioned into equal sections by black lines (Ref. 44). This field contained squares, diamonds, and triangles, the latter being the targets. Search time increased as the number of nontarget objects and partitions of the field increased. The results are shown in Fig. 32.

A circular display containing many small dots (circular pseudotargets) and one designated target (a square, triangle, hexagon, or pentagon) was used in a search experiment by Smith (Ref. 45). Typical results (for the square target) are shown in Fig. 33. It was also found that the triangle was the easiest target to find, and then in increasingly difficult order, a square, a pentagon, and a hexagon. In further experiments, peripheral discriminability of the targets was measured and compared to search time for that target (Ref. 46 and Fig. 34). It is seen that the easier it is to discriminate the target peripherally, the quicker it can be found in a display containing other objects.

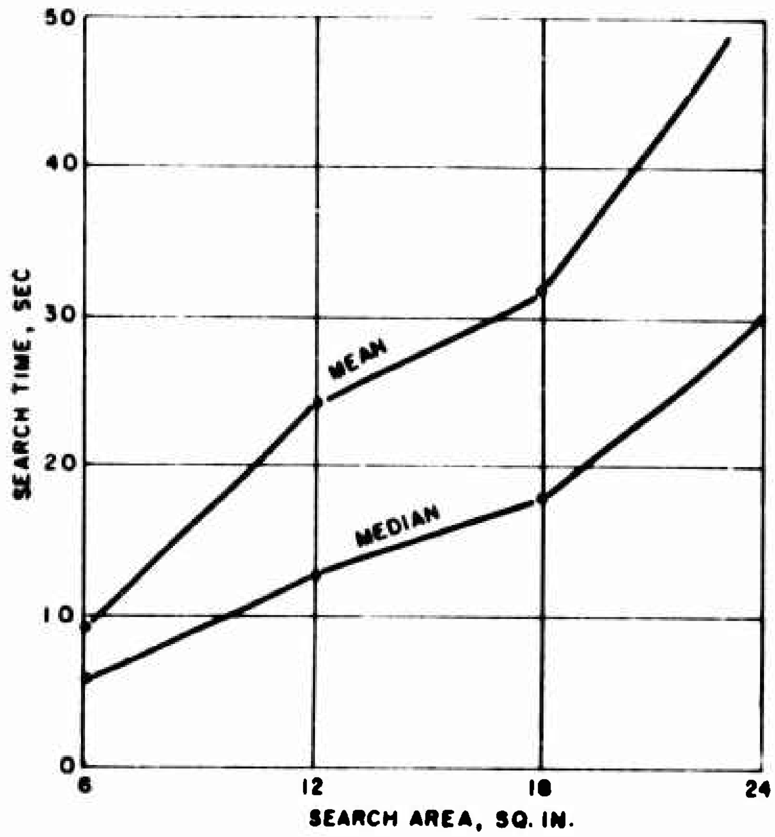


FIG. 31. Search Time Versus Search Area for Experiment by Baker, Morris, and Steedman.

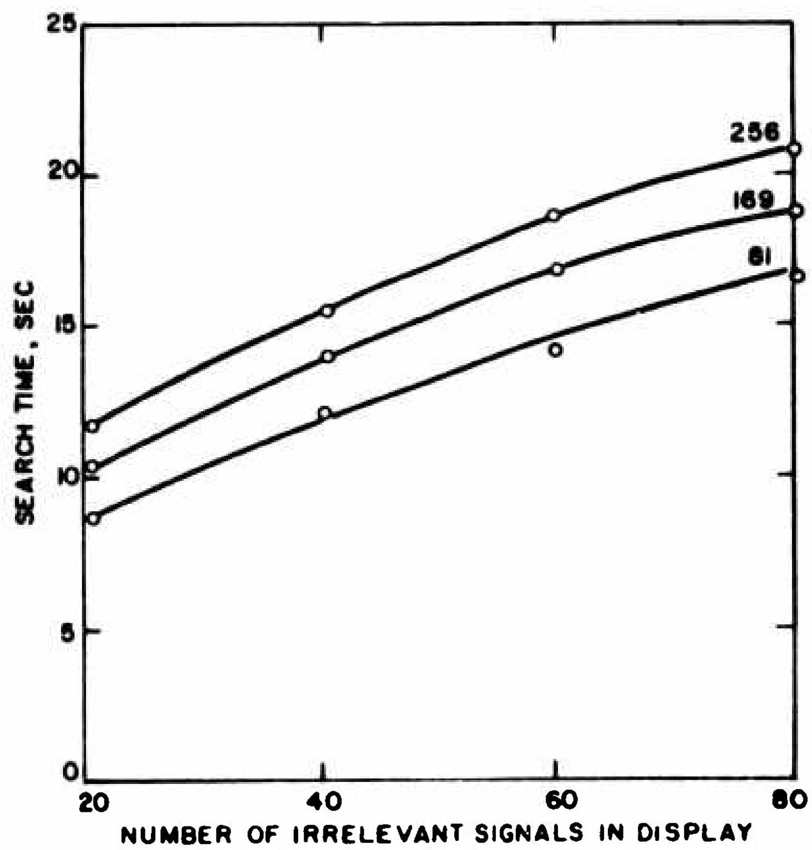


FIG. 32. Search Time as a Function of the Number of Signals and Partitions. Number of partitions in display are shown on each curve.

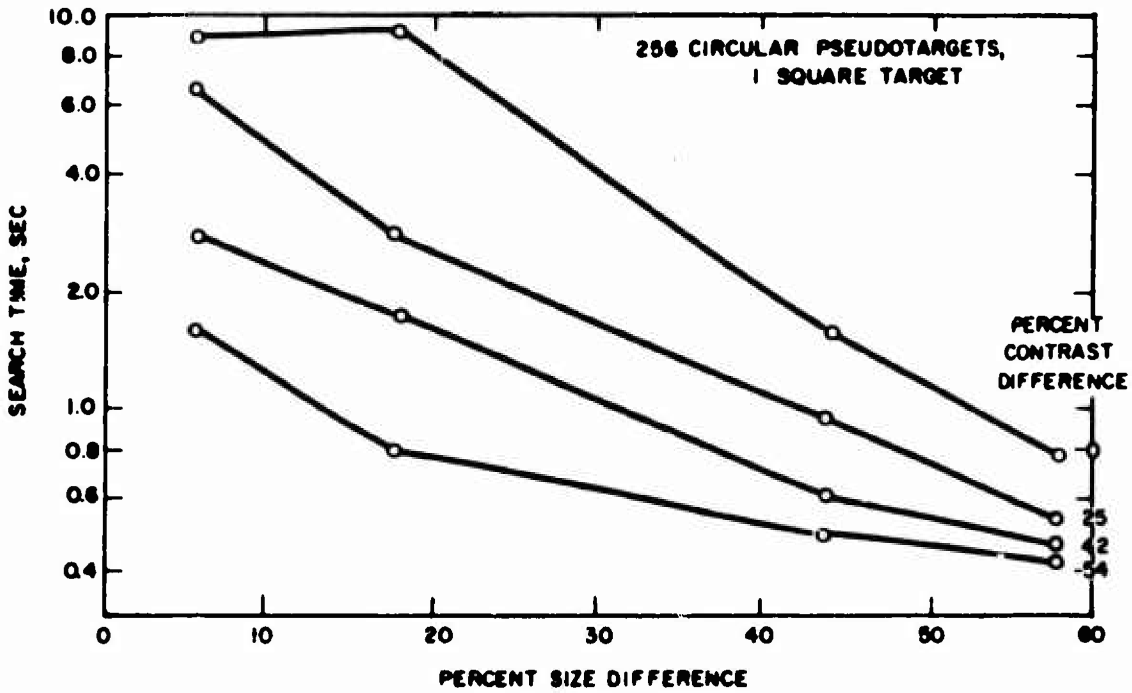


FIG. 33. Search Time as a Function of Target-Pseudotarget Size and Contrast Difference.

In three experiments described fully in Ref. 47, a peripheral visual acuity score was obtained for 16 subjects using a Landolt ring as the target. The time it took these subjects to find a target in a display containing other objects was also measured. Those subjects with the higher peripheral acuity (PA) scores tended to find the target quicker than those whose PA scores were lower, as was suggested by tests conducted by Smith, Boynton et al. Two types of displays were used: one contained "blobs" and the other rings. Search time was longer and less affected by object density for the blob displays than for the rings. The search task was repeated using only ring displays as part of the second experiment, and the average search times were much the same as those measured in the first. The third experiment employed a linear cue in ring displays by adding a black line to the display. The target was located somewhere along this black line. Search time decreased greatly and was not as affected by object density as it was in the displays without the cue. These search times are shown in Fig. 35.

Other studies of static search are included in Ref. 48 where such parameters as blur, eye movements, vigilance, and strategy are discussed.

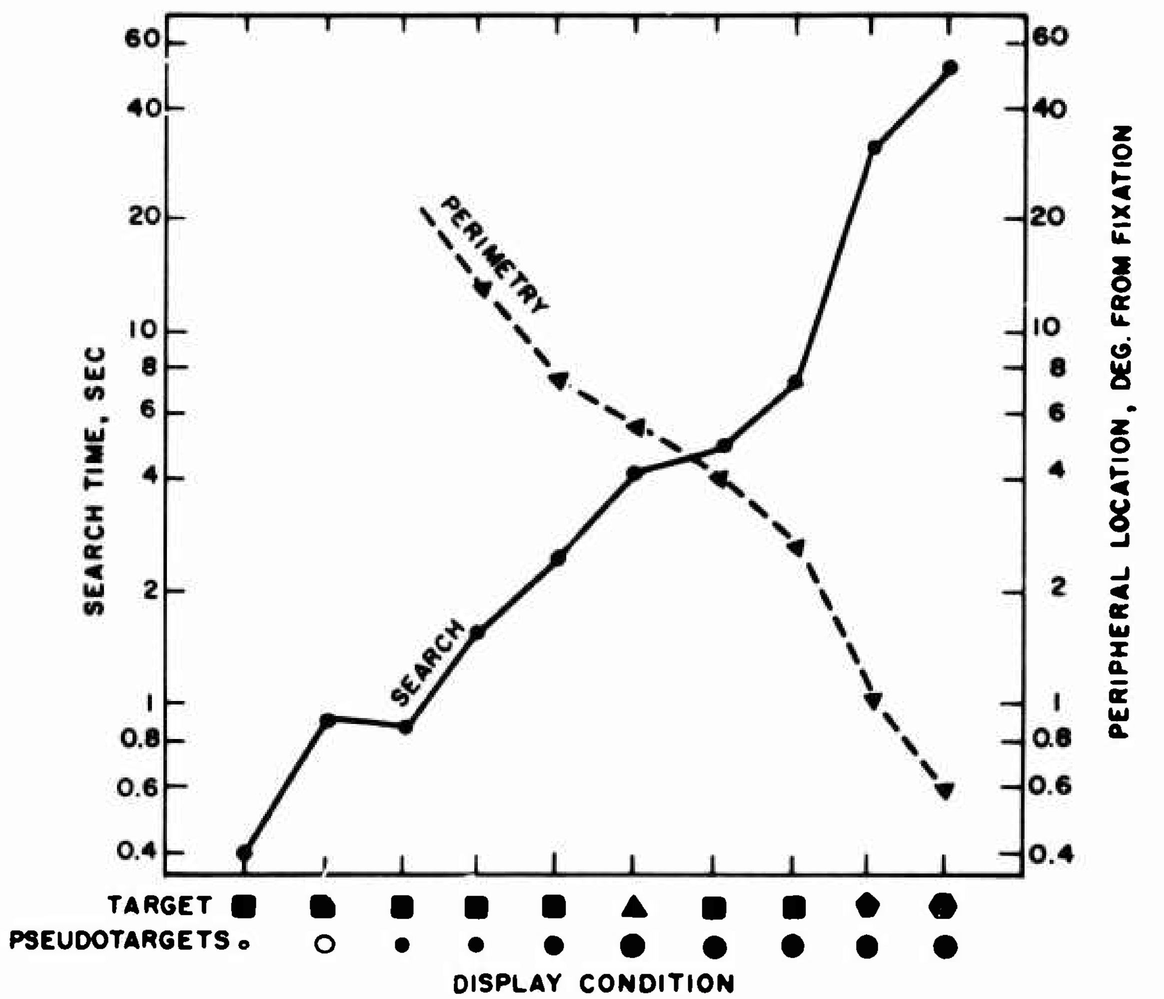


FIG. 34. Search Time Versus Peripheral Discriminability, From Smith (Ref. 46). Peripheral location in the figure is the distance from the point of fixation at which the target could be discriminated from a pseudotarget 75% of the time (50% corrected for chance).

MOTION AND VISUAL ACUITY

Ludvigh and Miller were the first to do considerable work with moving targets. A series of reports issued by the U. S. Naval School of Aviation Medicine, U. S. Naval Air Station, Pensacola, Florida, describe these studies. Some of the studies are also discussed in Ref. 49 and 50. Figure 36 shows that monocular visual acuity as measured with a Landolt ring deteriorates as the velocity of the target increases.

A good discussion of the work of others in the field and a presentation of the results of an experiment conducted at Tufts University is given in Ref. 51. Landolt rings were used as in the Ludvigh and Miller studies to determine dynamic visual acuity. Although acuity deteriorated with increasing velocity, it was found that lengthening the tracking time

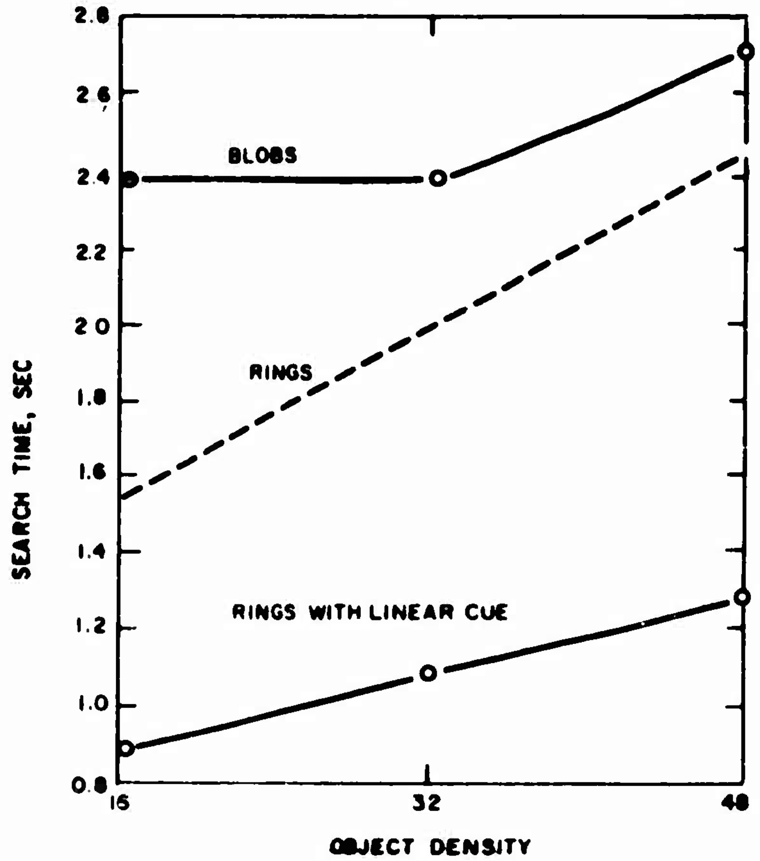


FIG. 35. Average Search Time on Static Displays, From Erickson.

or target exposure time, or both, slowed this deterioration. These conditions resulted in better acuity scores than in the Ludvigh and Miller studies.

In a study by Burg and Hulbert (Ref. 52), the target used was the checkerboard pattern of the Bausch and Lomb Ortho-Rater. The average dynamic acuity score was much better than that reported by Ludvigh and Miller. A different test object and binocular tracking over a longer distance may account for some of this difference.

In a similar study (Ref. 53), a Landolt ring projected upon a screen by a rotating projector was the moving target. The results were much the same as those reported above.

Display scale studies performed by Boeing Airplane Company (Ref. 54) indicated that an optimum display scale and an optimum viewing time existed for best target recognition. The curve is shown in Fig. 37.

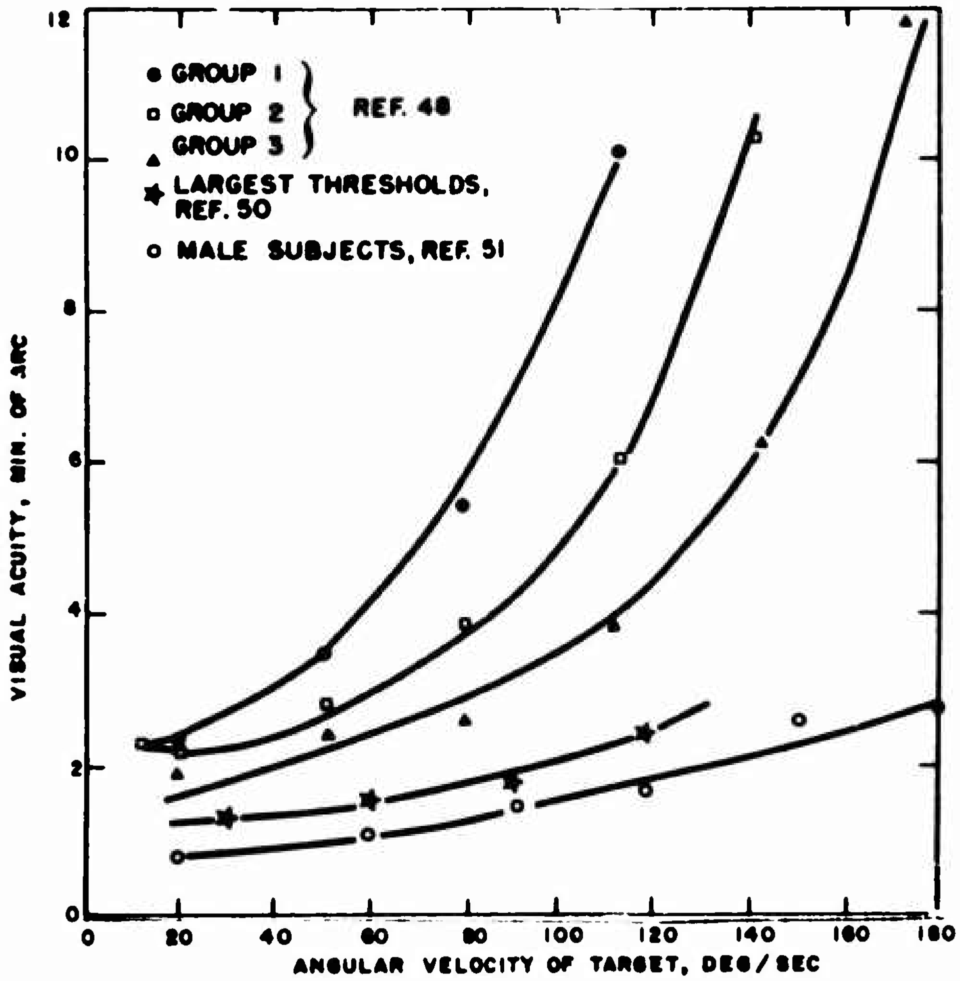


FIG. 36. Visual Acuity as a Function of Angular Velocity.

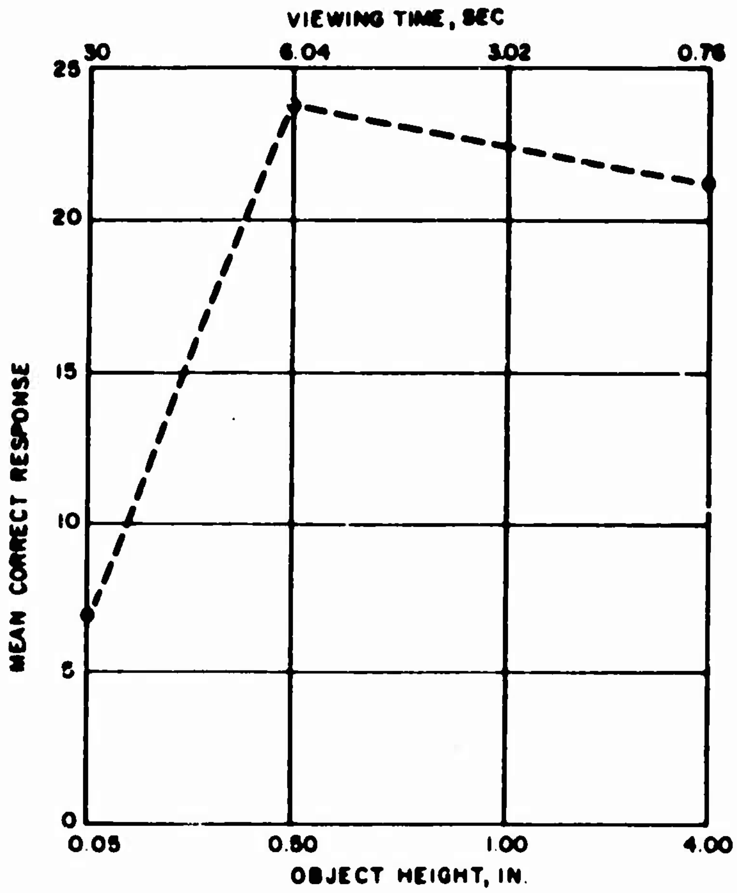


FIG. 37. Results of Display Scale Experiment of Kraft and Hamilton.

The legibility of moving letters and numbers was measured and results of the studies are reported in Ref. 55 and 56. Legibility thresholds are shown in Fig. 38. The symbols were moving in a column from top to bottom. In a later experiment, the relative legibility of the same letters was determined for velocities of 22.5, 31., and 36.0 deg/sec past the observer's eyes. Legibility rankings at all velocities were found to be significantly correlated with each other at the 0.001 level. No significant correlation was found with the rankings and the frequency of occurrence of letters in the English language.

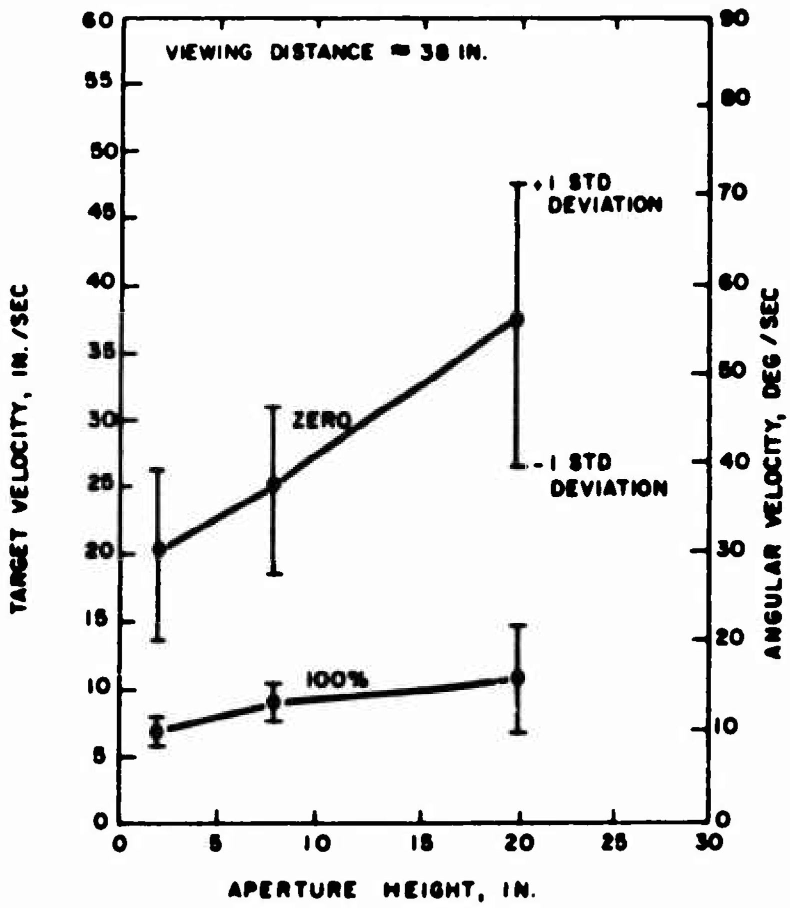


FIG. 38. Legibility Curves for Letters Subtending About 39 Minutes to the Observer.

After a review of research published in Ref. 57, it was concluded that targets moving across the visual field can be equated to stationary targets flashed on for a single brief exposure, equal in duration to the time required for the target to move across a point on the retina.

MOTION AND SEARCH

Visual target detection from an aircraft was simulated by making observations from moving automobiles in experiments reported in Ref. 29. Toy soldiers and vehicles were used as targets, and the geometry was equivalent to that encountered at a flight altitude of 100 feet. Reconnaissance scores were not appreciably affected by the speed of the automobile when the course was run at simulated speeds of 1,200 mph or less. The amount of actual searching in these tests is not known.

An experiment was performed at the Minneapolis-Honeywell Company using moving typewritten capital letters (Ref. 58). The same letters were always present in the field, which moved but did not change. Search performance began to decrease at display speeds between 8 and 16 deg/sec. The probability of locating the target, which was always within view somewhere in the field, is shown in Fig. 39. Again, it is seen that the higher the speed, the lower the probability of detection.

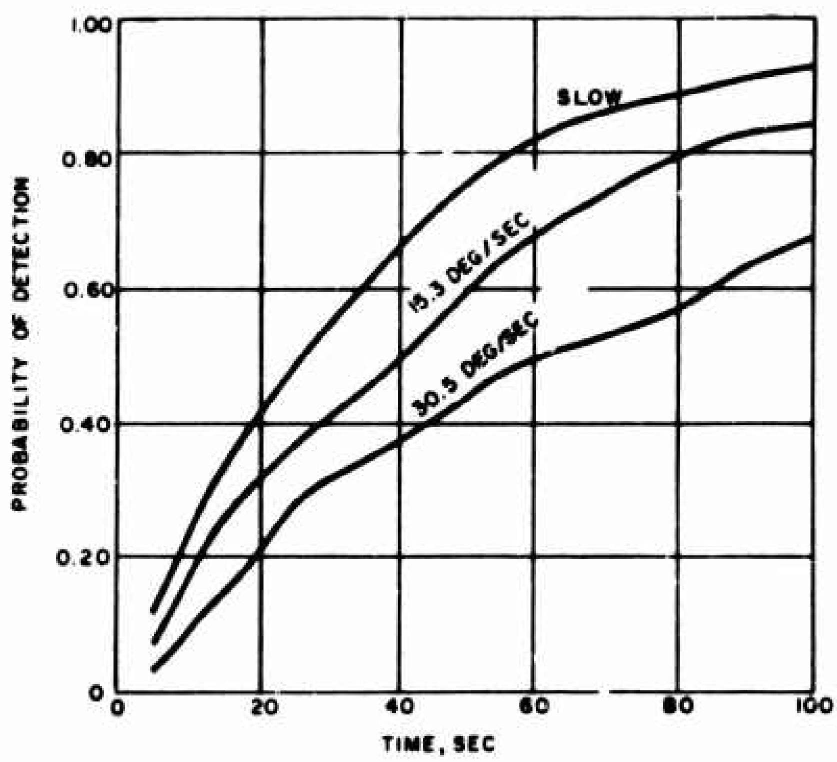


FIG. 39. Cumulative Probability for Each Speed for High-Density Field, From Williams and Borow (Ref. 58).

Some of the variables involved in detection of moving targets were studied in the experiment described in Ref. 47. The task was to detect the target, a Landolt C, among a number of solid rings. The rings were glued to a long white opaque belt that was moved vertically past a square window. Search performance generally deteriorated with an increase in belt velocity, ring density, or both. The probability of locating a target was strongly dependent upon its position in the display: the closer it was to the vertical centerline of the display, the more often it was detected. It was tentatively concluded that motion per se had no detrimental effect upon searching fields that were moving up to 10 deg/sec. The percentages of targets found in "equivalent search time" in moving and static displays were very much the same. This suggests the possibility of an extension of the statement in the previous section taken from Ref. 57 concerning apparent equivalency of detecting moving and static targets. For the velocities investigated, probability of detection appears to be the same when search also is involved. Foveal acuity seemed to be a better prediction of search performance than did peripheral acuity at the higher field velocities. The probability of finding the targets is shown in Fig. 40.

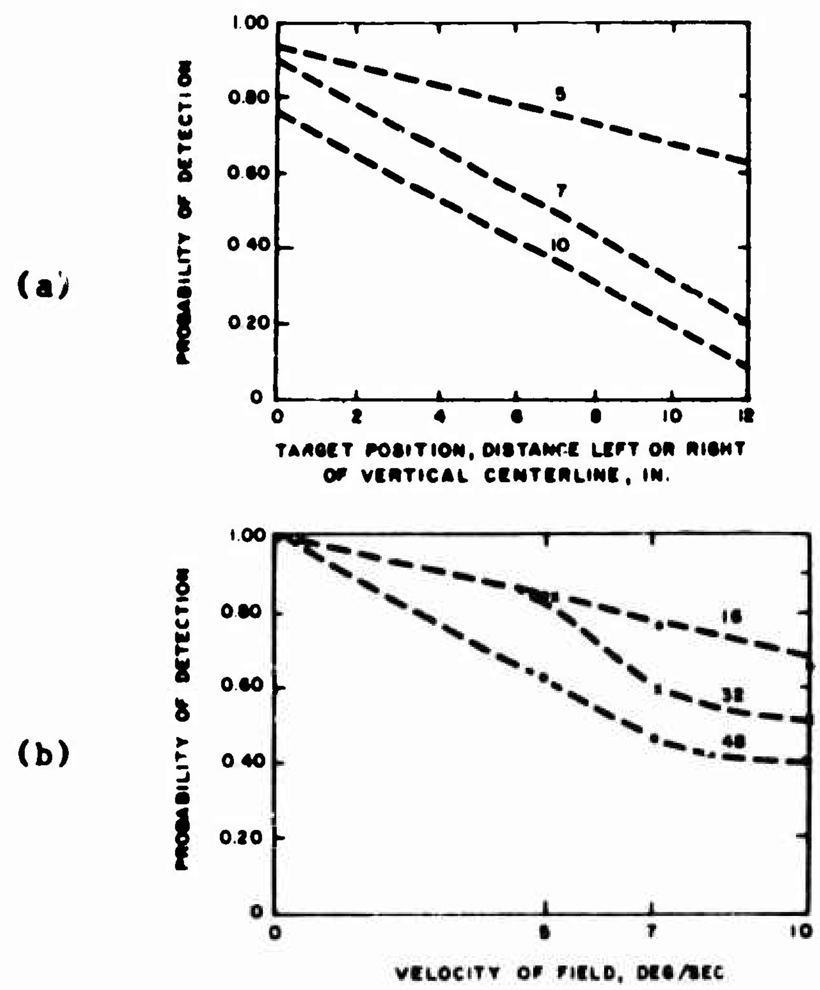


FIG. 40. Visual Search Performance in a Moving Structured Field. Velocity, in deg/sec, is shown on curves in (a); object density is shown on curves in (b).

SIMULATOR STUDIES

It appears that most laboratory studies yield data that are useful in answering academic questions rather than the operational questions encountered by the military. When no other information is available, such data are used in operational analyses; but if time, space, and the budget permit, it is preferable to gather data in a situation approximating the one of interest. Although the boundary between "academic" laboratory experiments and simulations is arbitrary, the author considers the studies described above to be more of an academic nature than operational, with the exception of the work reported in Ref. 29 where toy soldiers and vehicles were used as targets.

The study reported in Ref. 59 closely simulates a photo interpreter's task and might be considered to simulate, to a lesser degree, search from a high-flying aircraft, say 10,000 feet. In this study there were marked nonuniformities of display coverage by the observer. It was also found that the time needed to locate critical objects was markedly increased by degradation of the display resolution. A number of other findings were made regarding eye movements during search and are reported in more detail in the sources listed in Ref. 59.

Studies carried out on contract at Hughes Aircraft Company closely simulated photo interpreting tasks in which performance was measured as a function of display resolution (Ref. 60). It was concluded that since enlarging the scale has a detrimental effect at poor resolutions and a beneficial effect at better resolutions, the most effective means of improving the operator's performance is to increase display resolution. In an experiment conducted by the same group (Ref. 61), strip maps were moved past a window through which an observer was to search and identify specified targets. A fairly low percentage of targets were recognized at both display velocities used.

In an exploratory study reported in Ref. 62, it was shown that there was no significant difference in the performance of photo interpreters using different (vertical <u>or</u> oblique) or additional (vertical <u>and</u> oblique) views of the target area.

Reference 63 describes a simulator study using a rural landscape model built to a scale of 1:108. Small model tanks, other vehicles, and foot soldiers were used as targets. The experiments were run at two illumination levels: 0.02-foot candle (that of a three-quarter moon), and 2.0-foot candles (mortar flare). The influence of the light source position upon visibility was determined, and the simulated ranges of detection and identification were obtained for the various targets. It was concluded that a single flare may be more effective than a combination of flares since multiple flares in certain locations will attenuate contrast, thus reducing visibility.

A terrain model 10 feet on a side and built to a scale of 1:600 was used in the study reported in Ref. 64. An actual site within a park containing trees, grass, planted fields, buildings, and a number of roads was copied in the model. The target used was a convoy of three vehicles parked along a road. Data collected on this simulator were compared to data collected over the actual park using actual vehicles as targets and nine Navy pilots in RC-45J aircraft (at 130-knots airspeed) as observers. The probability of detecting the target both in the simulator and in the field is shown in Fig. 41. It is seen that there is a large difference between the laboratory data and the data collected in the field. However, the internal relations of simulator and field data were enough alike so that data for the former could be used to extend the usefulness of data gathered in the field.

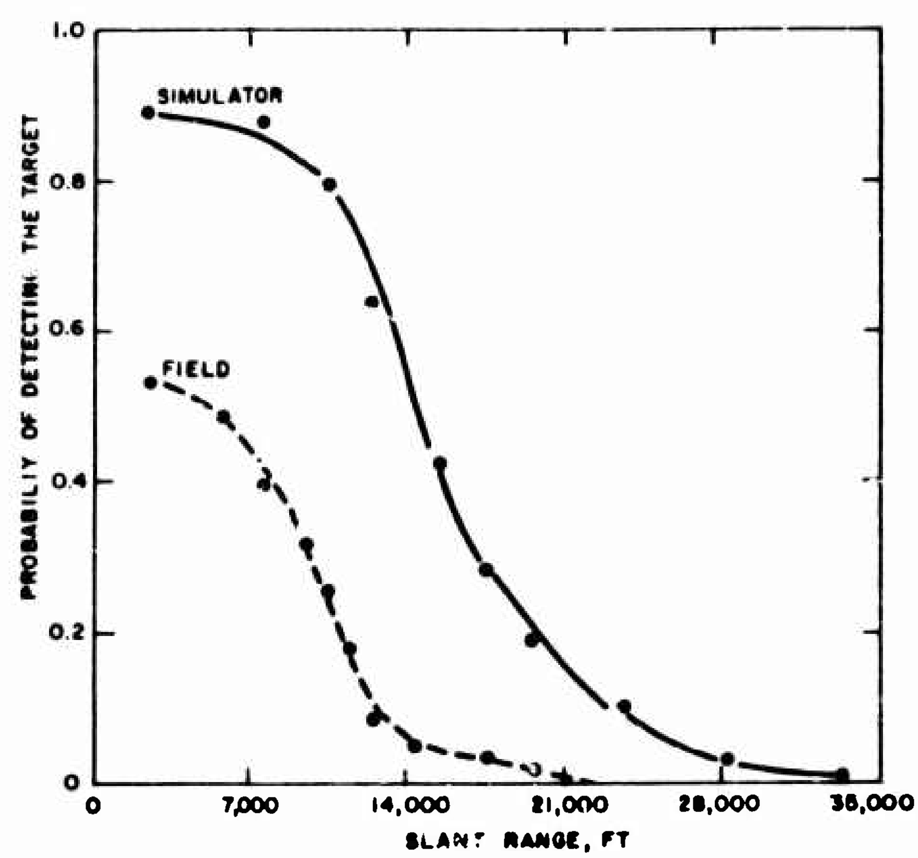


FIG. 41. Probability of Detection, From Ref. 63.

OPERATIONAL STUDIES

If there is a need for data describing human capabilities in air-to-ground search, the most reliable approach is to arrange for a number of humans to fly around in airplanes and collect data on their search capabilities. All variables would be present, such as time and attention necessary for actually flying the airplanes, vibration of the aircraft, air turbulence, and optical distortions by the windscreen and atmosphere. In spite of the difficulty and expense in such an undertaking, a number of such studies have been made. The study reported in Ref. 64 described in the last section is an example. Those data can be used for estimating the detection range of a three-vehicle convoy painted battleship gray and parked along a road. Other conditions, such as the 130-knot speed of the aircraft, must also be kept in mind.

A series of studies known as Project Longarm were conducted by George Washington University, under contract to the Army, and are summarized in Ref. 65. Targets such as riflemen, mortars, rocket launchers, jeeps, tanks, bunkers, and trucks were used in the tests. Forty-two observers were flown, one at a time, over the target area in an O-1A aircraft at about 92 mph and 350 feet above the ground. Targets smaller than 5 square milliradians were undetected by most observers; whereas targets subtending more than 50 square milliradians were detected if they were exposed for 5 seconds or more, were relatively unconcealed and were viewed under good visibility conditions. Targets were detected more frequently when they were moving than when stationary. It is further stated in Part I of Ref. 65: "Results from Project Longarm clearly indicate that, at low altitudes only (500-1,000 feet), aerial observer performance was lower at high speeds (275 knots) than for low speeds (87 knots)." This difference in performance almost disappeared at altitudes above 2,500 feet.

In a study reported in Ref. 66, it was found that the method of searching as well as the velocity of the aircraft carrying the observer affected search performance. Twenty-four observers searched for targets ranging in size from a tank to an automatic rifle. The observers were flown past the targets in an O-1A aircraft and an OH-23 helicopter at 200 feet above the ground. Four different methods of search were used. The results, shown in Fig. 42, were typical: performance decreases with increasing velocity, and some search methods are better than others.

Tests of target recognition capabilities from helicopters flying at or below tree-top level (contour flight) at 60 mph are described in Ref. 67. Tanks, jeeps, self-propelled guns (Scorpion), and mortar emplacements put in the field (variable terrain) in strategic defensive locations were among the targets used. Thirty-two pilots with aerial observation training or experience acted as observers in the tests, which were run from 7:00 a.m. to 5:00 p.m. Part of the results taken from Ref. 67 are shown in Table 2 and Fig. 43. The probability of detecting the targets is quite low, and the detection ranges are considerably shorter than many theoretical analyses have predicted.

A survey of the literature summarized in Ref. 68 revealed that conditions of field tests that have been carried out are so varied that combining the data to obtain a single estimate of search capabilities is risky. Nevertheless, in the absence of other estimates, this was done.

The results, which combine data collected from a number of altitudes, velocities, aircraft, targets, and terrains, are summarized in Fig. 44 and 45. The width of the curves reflects the confidence one might have in them.

Additional operational data that were not available for the summary given in Ref. 68, can be found in Ref. 69 and 70.

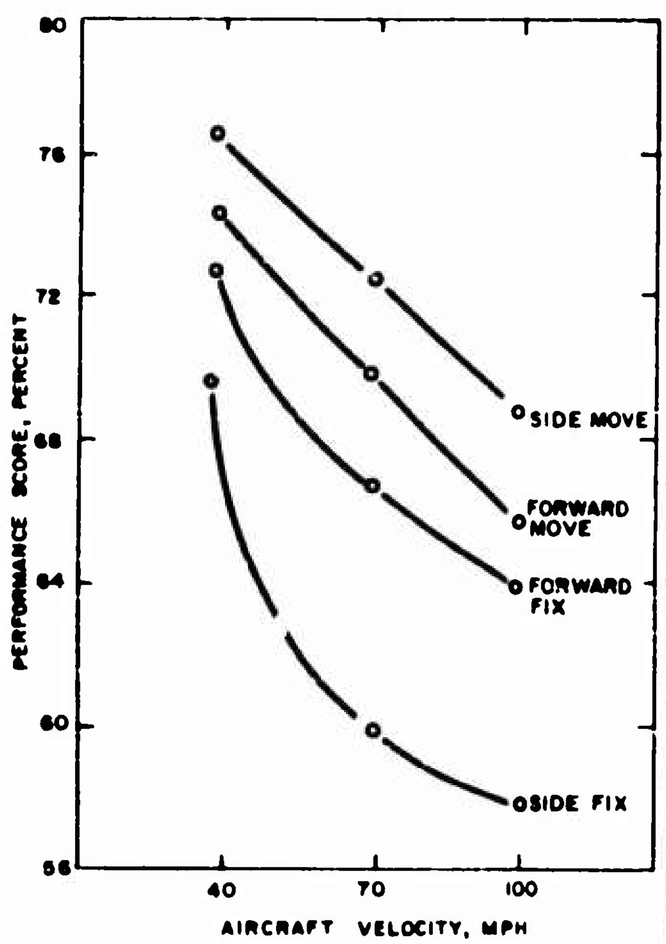


FIG. 42. Search Performance. Search methods are shown on curves.

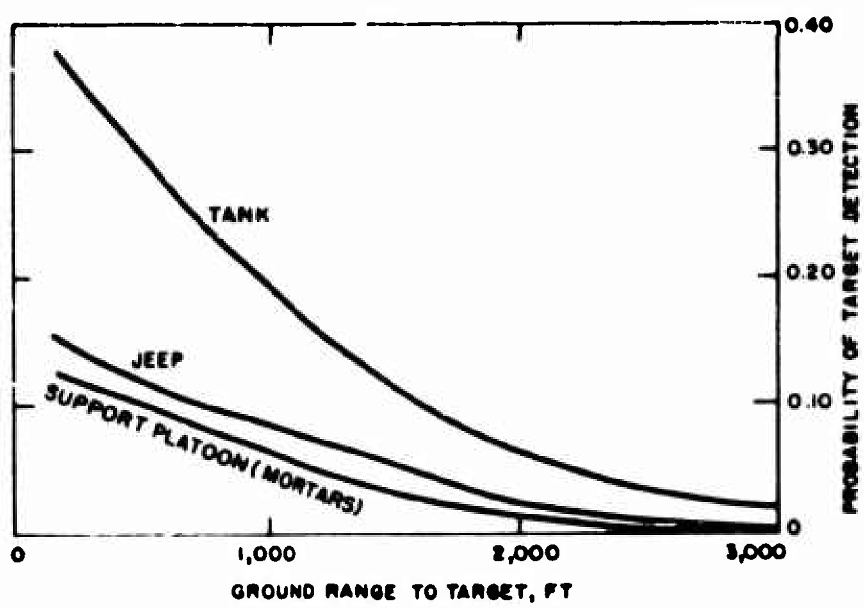


FIG. 43. Probability of Detecting Ground Targets From Contour-Flying Helicopters.

Enough such data do exist to provide a basis for some operational analysis estimates. It often seems, however, that for specific problems data do not exist, and tests must be run or preliminary estimates made from the results of using laboratory data in mathematical models.

TABLE 2. Probabilities and Ranges of Target Types

Item	Tank	Recoilless rifle	Support platoon	Scorpion	Machine gun
Probability of detection at or before 0-50 yard minimum range	0.38	0.15	0.13	0.12	0.06
Probability of correct identification	0.35	0.12	0.12	0.06	0.05
Maximum range of detection, yard	1,400	950	700	1,350	620
Range at which greatest frequency of detections occurred, yard	300	50	300	100	100

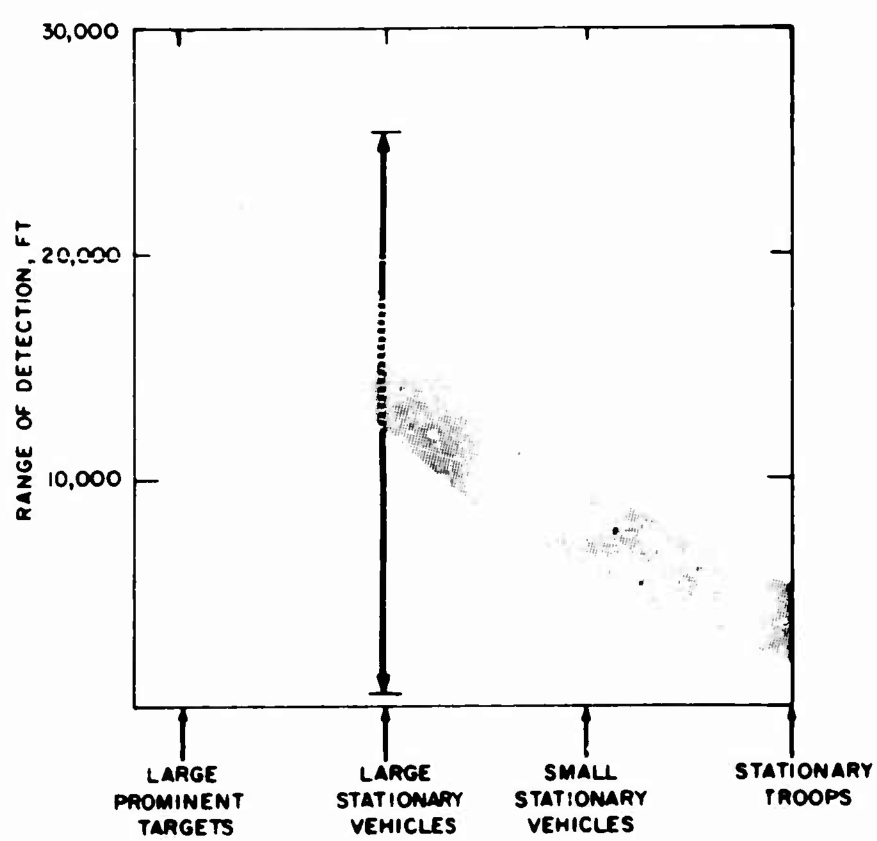


FIG. 44. Target Acquisition Ranges in Visual Air-to-Ground Search. As an example of the range of variables, arrows show the range of data collected at a particular point on each curve.

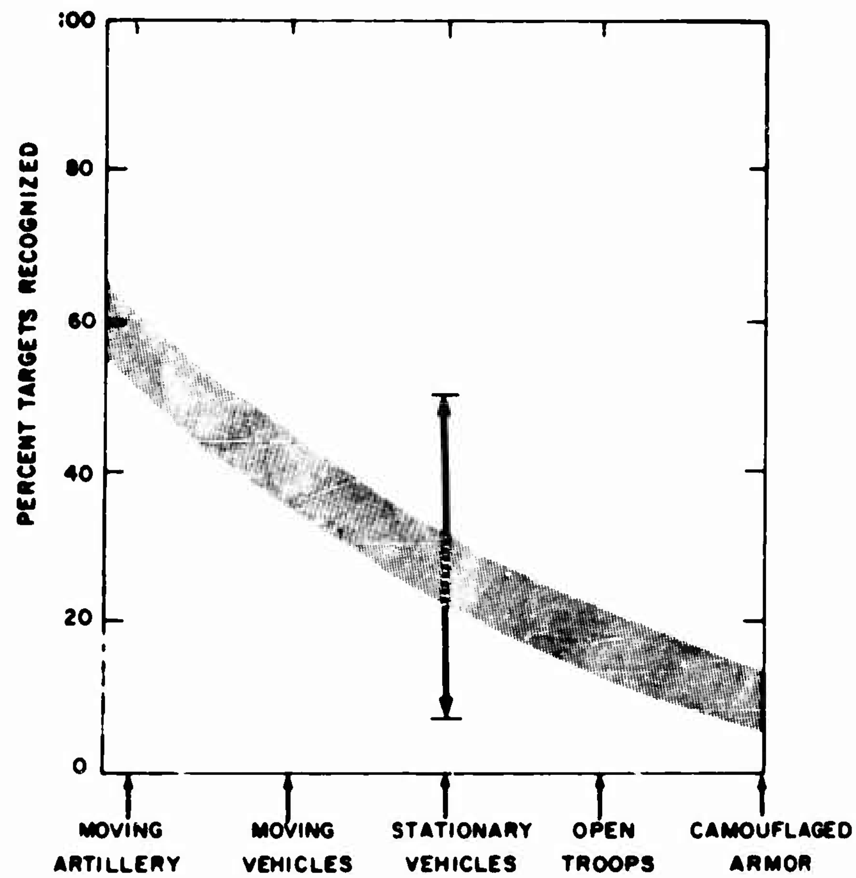


FIG. 45. Percent of Targets Recognized in Visual Air-to-Ground Search. Arrows show the range of data collected at a particular point on each curve.

MATHEMATICAL MODELS

Almost all of the material presented thus far in this report has dealt with direct measurements: cloud cover, atmospheric attenuation, terrain reflectance, and visual capabilities. If operational data similar to that discussed above are available, knowledge of such individual variables is unnecessary. When there are no applicable operational data, however, preliminary estimates are often made by calculating detection ranges according to certain assumptions regarding the search process. For example, consider the simulator and field studies already described in Ref. 64. Since the internal similarities of both were the same, a transformation factor was used to extend the range of the field-test results. This factor was determined between corresponding simulator and field data and then applied to values obtained on the simulator under conditions that had not been duplicated in the field. This operation, which appears to be direct and reliable, yields curves similar to those shown in Fig. 46.

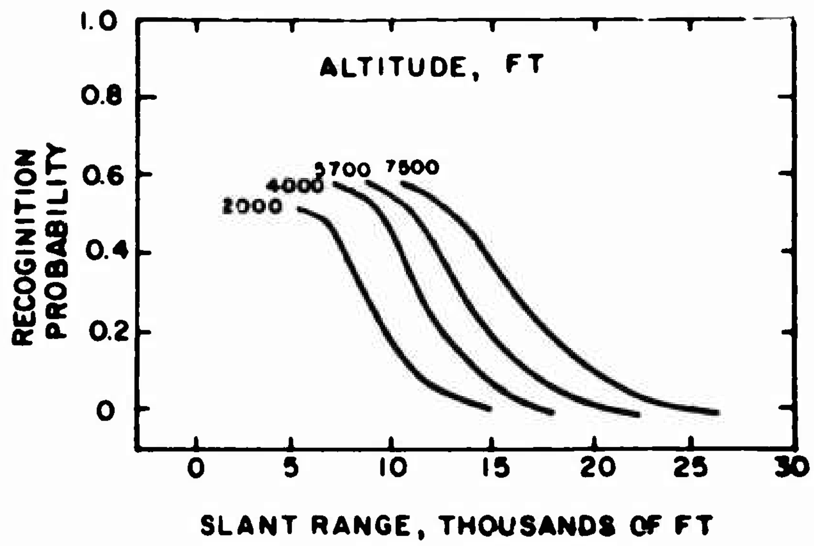


FIG. 46. Calculated Target Recognition Probability With 177 Degrees Between Sun's Position and Line of Sight.

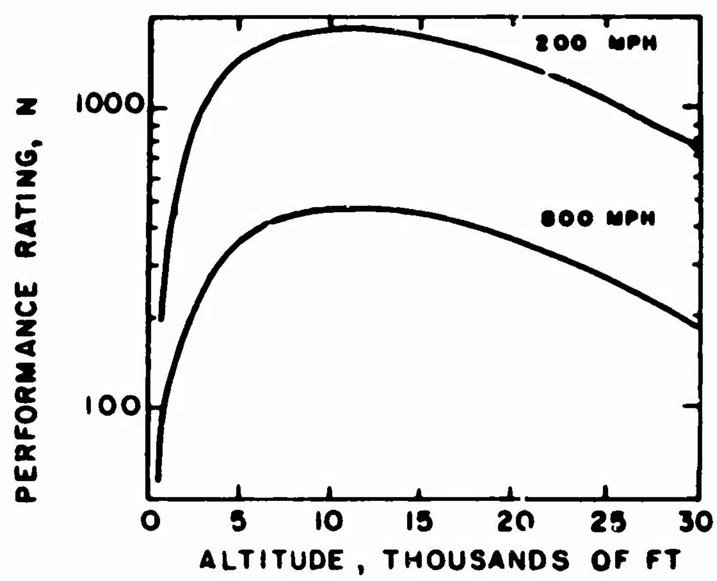


FIG. 47. Calculated Search Performance Rating as a Function of Altitude and Velocity for a 50-Foot Object, Such as a House.

Figure 47 shows the results of a process a step further from reality, where relative search performance was calculated from the results of laboratory experiments described in Ref. 40, 41, and 42 (see Static Search section). It was assumed that trends in search performance in a display similar to that shown in Fig. 27 are the same as trends encountered in the field. An optimum altitude of search for a given aircraft velocity and relative search performance at that altitude and velocity can be derived from the figure. It is suggested in Ref. 42 that the range of field data could be extended by using this model, as was done in the field and simulator studies described above.

The personnel at Scripps Visibility Laboratory also use the results of experiments performed specifically to gather data for a mathematical model. Detection and recognition ranges of targets are calculated from inputs such as atmospheric attenuation data, target-background contrasts measured with either a small model or the actual target, sun's angle, visual thresholds measured in the laboratory, and others. An example of such a study is given in Ref. 71, where the detection and recognition ranges of a tank and a radar van are calculated. These ranges will be compared to data gathered in the field in a program being carried on at NOTS to evaluate the Scripps visibility model. The summary report will be issued by NOTS late in 1965.

The comparison of field test results to simulator results described in Ref. 63 is the only such check on direct visual performance discovered in the literature. Similarly, the NOTS-Scripps studies will produce the only known check on a mathematical model.

A number of studies using data available in the literature have been conducted, examples of which are Ref. 72 and 73. In Ref. 72, the detection probability of a tank seen end-on has been computed using specified meteorological visibility, sky-ground brightness ratio, duration of fixation time per glimpse, target-background contrast, and aircraft velocity. In addition, a confusion factor (CF) is introduced into the calculations to account for search when other objects are in the visual field. It is not clear how a value is selected for the factor, however. Curves similar to those shown in Fig. 48 are given in the report. Apparently, the model has not been verified by even the simplest experiment.

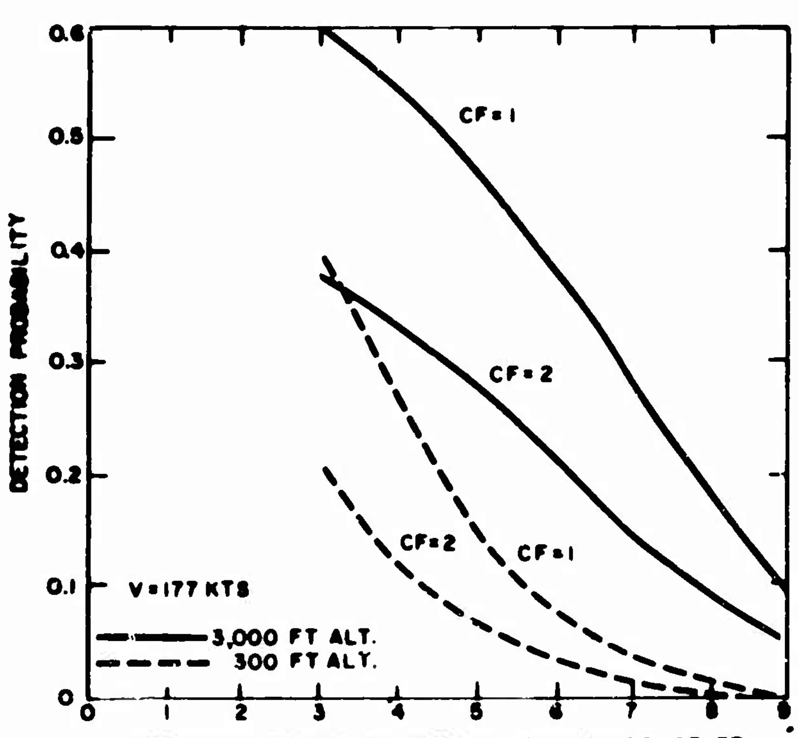


FIG. 48. Accumulative Detection Probability Against a JS-III Tank in an Area 600 by 600 Yards. The assumed confusion factor, CF, is shown on the curves.

A more complicated model described in Ref. 73 can be applied to recognition of targets by direct vision or with television, infrared, or radar sensors. The complexity is indicated by the use of some 198 symbols in this model, including a probability of target recognition by an observer while monitoring some particular sensor display during a particular interval. The formulation of this probability is based upon the work of Boynton et al reported in Ref. 42. The model is programed so that it can be solved on the IBM 7090.

A number of additional reports dealing with visual detection, issued by contractors or government agencies, are listed in the bibliography. Although such reports, including those described above, vary in their content and probable accuracy, they all have one thing in common: their conclusions or results have not been checked in the field. Furthermore, in some cases the assumptions made are questionable. Choice of experimental data upon which to base model formulation is but one of the problems. As an example, consider some calculations of search efficiency from a moving aircraft that were based upon Ludvigh and Miller's dynamic acuity data. If, instead of Ludvigh and Miller's data, the data from the experiments by Elkin or Berg and Hulbert had been used, the estimated search performance would have been much better.

SUMMARY: SOLUTIONS TO OPERATIONAL PROBLEMS

The necessity of estimating human visual capabilities occurs frequently in weapon feasibility and design studies and in weapon and tactics effectiveness studies. Other programs such as flare development and test also require a knowledge of visual capabilities. In some cases, consideration of geometric or kinematic parameters will suffice. As an example, consider the evaluation of a tactic of delivering a weapon on the first pass over a small target from an altitude of 200 feet above the ground. Reference to Fig. 5, 6, and 7 will reveal that the probability of the target's being within view is low until the aircraft is quite close to the target. Unless the flight path is directly over the target, there would probably not be sufficient time to change direction and track the target before weapon release. Hence, it can be estimated without knowledge of human visual capabilities, that the tactic has too high a probability of failure.

Similarly, the frequency and height of cloud cover in typical target areas may preclude the use of certain tactics or systems. If such is the case, to go a step further and assess visual capabilities is unnecessary.

ACQUISITION, DETECTION, RECOGNITION

Most of the time, however, it is not so easy to solve the problem, and a knowledge of visual capabilities is required. The first step is to decide precisely what is needed.

Too often terms are used without being even superficially defined, leading to ambiguous results, particularly when the human system (with its associated subjectivity) is being discussed. The process of delivering a weapon includes searching for the target, detecting an object that could be the target, inspecting the object, and deciding whether it is the target. If the object is accepted as a target, recognition is said to have occurred. The next step is to enter the delivery mode and track or lock on the target. Target acquisition might be defined as the entire process of search, detection, inspection, and target recognition. In some applications, the term target acquisition includes the ability to locate the target (on maps, with respect to some terrain features, with respect to the aircraft, etc.). In other applications, target acquisition is defined to include the lock-on phase.

However, precise definition of these words in this report is not appropriate since no particular situation is being discussed, and one definition is not applicable to all existing data. Current concepts include a probabilistic approach which is perhaps most applicable to the operational situation. The most accurate interpretation of data is based upon such an approach. If a tank has been reported in a certain area, and the searching pilot detects a large dark object in the area, he may be willing to enter the attack mode. If tanks have been shooting at airplanes, the pilot might be willing to fire at maximum range, before he can actually see enough detail in the object to state at some level of confidence that it is a tank. If the enemy has been using decoys, missile launching may be delayed until recognition at a higher confidence level (say 50%) is reached. If friendly forces are in the area, firing may be delayed until the pilot is close enough to say with 100% confidence that the object is an enemy tank. Since the same process occurs in any field test, motivational factors must be considered. Motivational missmatch between field tests and combat is probably inevitable, but efforts should be made to minimize it.

USEFULNESS OF DATA

Where a large number of data points are available, and are normally distributed, reporting the mean and standard deviation is sufficient. In practice, especially with field tests, the number of samples is usually small and normality cannot be assured. It is therefore most helpful to report all the data or to show the distribution of the data (histogram). Tests for significance of effects should be included when applicable, but it is also important to present the data itself. To show that some performance at 100 knots is significantly better (at, say, the 0.001 level of significance) than at 200 knots is not enough for a decision. If performance (say, range at target detection) is improved only 10% by slowing down to 100 knots, it may not be worth the disadvantages incurred, whereas a 300% improvement would be.

MATHEMATICAL MODELS

It appears that the initial reaction to awareness of the need for data on target acquisition capabilities is to derive some equations and calculate all of the necessary data. Factors such as human visual acuity and contrast threshold, lighting, atmospheric attenuation, target size, and target background reflectances, are usually included even by the beginner. As the theorist studies the problem further, he includes stimulus duration, peripheral acuity (detection lobes), and target shape. The finishing touches are added by throwing in internal visual content (contrasts) of the target, nonuniform background, and search techniques with a dash of probability theory. Often a "fudge factor" is applied to cover fatigue, motivational, and other effects. If intermediate sensors are used, applicable parameters such as signal-to-noise ratio, lines per inch, and contrast attenuation, are added to the equations. With some notable exceptions, the results of these calculations are never checked in the field.

Independent comparison of the results with existing field data (however meager) shows that errors of 100% are common. Errors of more than 100% are even more common. (It might be noted that many of these errors are in the favor of whatever missile system is being proposed at the time.)

Efforts to apply analytic methods to the target visibility problem should continue, and support should be given to those proficient in the field, such as Scripps Visibility Laboratory. Such efforts should be recognized as being in an exploratory research phase, however, and should be treated as such. Basing missile design on the results of such calculations can easily result in the waste of more money and time than would be consumed by a properly planned flight-test program that would provide more reliable data.

LABORATORY TESTS (SIMULATORS)

Field conditions can be simulated to varying degrees of fidelity in the laboratory and performance f subjects can be measured. Simulation of the target acquisition process can range from use of abstract, two-dimensional displays (containing circles, squares, numbers, letters, etc.), to complete three-dimensional terrain models containing trees, roads, grass, houses, and an adjustable "sun". There are a number of such simulators in this country and many reports have been issued giving results obtained with them. These results are almost never checked, even partially, in the field.

Simulator studies are valuable for determining trends to be expected in the field, provide a valuable background and partial understanding of the problem of planning field tests, and can be used to extend field data under the proper conditions. But using simulator data as the only input to analyses of operational problems (which usually require absolute, not relative numbers) is unwise when there is any feasible alternative.

FIELD TESTS

A field test is, in most cases, also a simulation of a desired combat situation.

Although it is not often done, the physical situation can be duplicated (as on the Coso Test Range, at NOTS) so that one might say this is not a simulation. Differences in motivation and stress, for example, do exist, and probably make the results noticeably different from those which would be obtained in war.

In mathematical models, relationships and values of parameters can simply be assumed, and calculations made. In laboratory studies, factors can be closely controlled and a large amount of data can be gathered. In the field tests, however, adequate control of the variables is often difficult or impossible, and the number of conditions that can be investigated as well as the number of runs at each condition is limited by practical factors. These factors must be kept in mind when planning field tests as well as when judging the usefulness or applicability of field-test results to weapon analyses.

Although the only real solution to an operational problem is a field test, the material presented in this report is helpful in planning, conducting, and evaluating field tests, and might be used to some degree to extend the test results.

The information presented in this report can be placed in two categories: (1) factors affecting air-to-ground detection and recognition ranges and probabilities and (2) past attempts to determine these ranges and probabilities. The first category is simply a presentation of examples of available data from analyses, field measurements, and laboratory studies. The second describes studies of collection and interpretation of test data for various applications and, in some cases, the use of data from the first category for estimating performance levels in operational situations. The second category, which produces results with direct application to military problems, is by nature more controversial.

It is hoped that the results of the operational studies described or referenced in this report will be useful in answering design evaluation, or tactical questions. The curves showing obstruction of view and angular rates of the field can be used alone or in combination with the reported field-test results in various types of operational analyses.

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